DOCUMENT RESUME

ED 160 490 SO 011 084

AUTHOR Crosson, Pierre R.; Frederick, Kenneth D.
TITLE The World Food Situation: Resource and Environmental Issues in the Developing Countries and the United States. Research Paper R-6.
INSTITUTION Resources for the Future, Inc., Washington, D.C.
PUB DATE 77
NOTE 239p.; Parts may be marginally legible due to type size
AVAILABLE FROM Johns Hopkins University Press, Baltimore, Maryland 21218 ($6.00 paperbound)

EDRS PRICE MF-$0.83 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS Agricultural Production; Depleted Resources; *Developed Nations; *Developing Nations; Economic Climate; Environmental Influences; Farm Management; *Food; *Futures (of Society); *Global Approach; Government Role; Land Use; Natural Resources; Pesticides; Population Growth; Tables (Data); Technological Advancement; Water Resources; *World Problems
IDENTIFIERS United States

ABSTRACT

The book provides an overview of the food situation in developing nations and in the United States as it will be until the end of the 20th century. Specifically, the research focuses on interrelationships among world food needs, resources, and environmental issues. The document is presented in seven chapters. Chapter I presents background on the global food situation and summarizes the rest of the book. Chapter II discusses how food production can be managed so that it will meet global demands. Topics discussed include regional differences, levels of food consumption, food imports, grain harvest, and malnutrition. Chapter III examines resource and technological factors underlying agricultural expansion in developing nations. Chapter IV examines environmental impacts of agriculture, such as soil erosion and loss of productivity, salinity, pesticides, pollution, and silting in irrigation systems. Chapter V identifies environmental impacts which may result from efforts of developing nations to increase food production. Chapter VI examines projections to 1985 by the U.S. Department of Agriculture relating to crop production in the United States. The final chapter focuses on environmental impacts and policy issues in the United States associated with land use, fertilizers, pesticides, and irrigation. (DB)

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The world food situation

Resource and environmental issues in the developing countries and the United States

PIERRE R. CROSSON and KENNETH D. FREDERICK

RESEARCH PAPER R-6

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Library of Congress Catalog Card Number 77-90817
ISBN 0-8018-2062-6

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Published October 1977. $6.00.

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Acknowledgments

We are grateful for comments on earlier drafts of this report from Martin Abel, Howard Cottam, Ralph Cummings, Dana Dalrymple, Erik Eckholm, John Hyslop, Charles Pearson, Shyamal Roy, Fred Sanderson, Andrew Schmidt, Earl Swanson, and Harry Walters, and from our colleagues at RFF, Emery Castle, Marion Clawson, Leonard Fischman, Lincoln Gordon, Hans Landsberg, Herbert Morton, and Patricia Rosenfield. Many of these comments have been incorporated in the present draft, which is substantially revised from earlier ones. Since none of the people named have read this draft, the usual assertion by the authors of responsibility for the results carries especially heavy weight in this instance.

We also wish to thank Debbie Hemphill, Christine Lain, Helen-Marie Streich, and Peggy White for their patience and skill in typing this and earlier drafts of the report.

Chapter 1

BACKGROUND AND SUMMARY

Concerns regarding the global food situation have gone virtually full cycle during the 1970s. At the start of the decade, grain reserves were large, food prices relatively low, and U.S. agricultural policies designed to restrict output and support growers' prices. The situation changed abruptly when world food production on a per capita basis suffered its sharpest decline in twenty years in 1972, and the crisis atmosphere initiated by these crop failures was prolonged by further major crop failures in 1974. By 1973/74 total grain stocks were only 10 percent of apparent consumption compared to 19 percent four years earlier, grain prices were two to three times the levels of two years earlier, and the United States had removed all production constraints on its farmers. More recently, the record global grain harvest in 1976/77 and expectations for another large harvest in 1977/78 have eased, at least temporarily, concerns regarding global food adequacy. Grain prices during the first quarter of 1977 were 10 to 50 percent below their levels of two years earlier measured in nominal terms; the real declines were considerably larger. World wheat and coarse grain stocks in 1976/77 were nearly 50 percent above the levels of the previous year, and in 1977 agricultural policy debates in the United States once again centered around the appropriate level of agricultural price supports and the need for acreage restrictions.

The food crisis refueled a long-standing debate as to the ability of agricultural output to keep pace with needs. The neo-Malthusians emerged in force during the recent food shortages. In their view the crisis was largely the result of long-term forces and trends which include declining

quantities and qualities of unused land and water resources, rising prices of fertilizer, energy, and other productivity increasing inputs, declining additional benefits from new agricultural technologies, and perhaps even deteriorating climatic conditions for agriculture. Their argument concludes that it will be increasingly difficult and costly to expand world food production to meet future demand. The contrary view holds that the recent crisis can be attributed primarily to an unusual combination of short-run phenomona and that technological change will enable food production to keep pace with demand without significant real cost increases.

Most of the experts now seem to agree that primarily short-run factors, especially adverse weather in important agricultural areas, were responsible for the recent food crisis. However, the apparent recovery from the crisis, as measured by declining grain prices and rising stocks, was due more to slow growth of demand since the early 1970s than to unusually good production performance. From the beginning of the 1960s to 1971/72-1973/74 world consumption of grains grew by about 3.3 percent annually. From 1971/72-1973/74 to 1976/77, however, consumption of grains increased at an annual rate of only 1.6 percent. Much of the slowdown in consumption growth reflects a decline in the amount of grain fed to livestock in the United States, although other components of world demand for grains also grew more slowly. Production of grains grew about 3.0 percent annually from the early 1960s to 1971/72-1973/74 and about 2.8 percent per year from 1971/72-1973/74 to 1976/77. If consumption had continued to grow at the earlier rate the increment of consumption between 1971/72-1973/74 and 1976/77 would have been 166.5 million metric tons of grains, 16 million metric tons more than the increment of production. The actual increment of consumption was 79.3 million metric tons, 61.4 metric tons less than the increment of production. Clearly, if consumption had continued to grow at the earlier rate, the pressure

on world production capacity would have been much greater than it was, grain prices would not have fallen as much, or at all, and stocks in 1976/77 would have been much less than they were.[1]

These considerations suggest that the decline of grain prices and increase in grain stocks in 1976/77 do not rule out the possibility or even the likelihood that longer-term trends in food consumption and production imply persistent difficulties in meeting the food needs of future generations. Indeed, the debates as to the causes of and solutions to the recent food crisis highlighted important gaps in our knowledge regarding the factors likely to affect the rate and costs of future food increases. Areas of uncertainty include the costs, both economic and environmental, of bringing new land and water resources into production, the productivity of these resources under alternative technologies, the long-run implications of current and anticipated rates of ground water depletion, erosion, pesticide and fertilizer use, and salinity, the possibilities for adapting and adopting existing technologies to new environments and crops, and the long-run impacts of high energy costs. Our understanding of these factors is an important element in our capacity to develop an effective long-run agricultural development strategy.

The focus of this research paper is on the resource and environmental factors likely to affect food production in the developing areas and the United States to the end of this century, although for the United States our projections extend only to 1985. This focus does not indicate that we believe other factors and regions are unimportant to the long-term global

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[1] All data are from U.S. Department of Agriculture (USDA), The World Food Situation, p. 18 and USDA Foreign Agriculture Circular, p. 40. If consumption had increased at the earlier rate, prices would have been higher; consequently production probably would have grown faster than it did in fact after 1971/72-1973/74. However, the slowdown in production growth after those years was slight, 2.8 percent annually compared to 3.0 percent from the early 1960s to 1971/72-1973/74. It seems unlikely, therefore, that even with more favorable prices production would have grown much faster than it did.

food outlook. We readily concede the tremendous importance of the institutions affecting both the motivation of individual farmers and the overall efficiency with which a nation's human, financial, and natural resources are used in agricultural production. However, these factors are not examined in this paper.

The paper summarizes the initial or reconnaissance phase of our research. While the paper offers no new data or analyses to narrow the areas of uncertainty clouding the future food outlook, we hope that the systematic presentation of the demand, resource, and environmental issues and their interrelationships will help clarify some of the problems, policy options, and research needs for meeting the challenge of adequately feeding future generations at acceptable costs.

Summary of the Study

To set the stage for the subsequent analysis of the resource and environmental issues, chapter 2 examines the magnitude of the effort required to increase world production in step with food demand to the end of this century. The challenge is great since world food demand by the year 2000 should be more than twice the 1970 level. High population growth rates and low initial consumption levels in the developing nations indicate that the major global challenge will be to raise the average level of food consumption in the low-income areas. If the developing areas achieve what we believe should be minimum objectives for average dietary levels, these areas will account for about three-fourths of the total growth in world food demand to the end of the century. To achieve these consumption increases, the developing areas must either accelerate the growth of their own production or become increasingly dependent on food imports.

Chapter 3 examines the resource and technological factors underlying both the potential for and the costs of agricultural expansion in developing areas. Surveys of land and water potential suggest that the developing areas as a group possess abundant unutilized land and water resources with agricultural potential. The distribution of these natural resources in relation to population, however, is very uneven. While Asia accounts for more than 70 percent of the population, it possesses less than 11 percent of the unutilized agricultural land potential of the developing areas. Thus, agricultural development options in most of Asia are limited essentially to increasing the yields on lands already in cultivation. While agricultural development in much of Africa and Latin America is not so constrained, the costs of bringing their vast virgin land and water resources into production and the productivity of these resources under alternative technologies are uncertain. Estimates of global and regional resource availability provide little insight as to either the likely costs or the desirable patterns of agricultural development in various regions. Yet, examination of the resource situation leaves little doubt that efforts to expand agricultural production along traditional lines soon would encounter rising costs that probably would frustrate efforts to accelerate agricultural growth. Technological change both to increase yields on currently cultivated lands and to bring new lands into production is the key to success in these efforts. The potential to overcome specific resource limitations and forestall the advent of diminishing returns in agriculture through technological change has been demonstrated in many countries. Unfortunately, technologies which help revolutionize agriculture in one area seldom are applicable directly to another area. Additional research is required to adapt technologies to the environments

and factor proportions of different regions. The relevance of existing technologies to the tropical environments characteristic of much of the unutilized land resources is even more remote. Furthermore, since the technologies associated with high productivity agriculture are energy intensive, high energy costs will keep upward pressure on production costs and could slow the development and rate of adoption of new technologies. Nevertheless, well funded, managed, and planned research efforts can provide the developing areas with the potential to increase agricultural production in step with demand to at least the end of the century. If the potential is to be realized, however, the institutional shortcomings which divert resources out of agriculture or discourage their efficient use within agriculture must be eliminated.

Chapter 4 describes briefly the most important environmental impacts of agriculture--those resulting from soil erosion, salinity and other effects of irrigation, fertilizer and pesticide pollution, and others—and makes two principal points about them. The first is that these impacts on the environment exact real social costs, for example in loss of soil productivity, reduced electric generating capacity and damage to irrigation systems from accelerated siltation of reservoir and canals, and illnesses and deaths resulting from pesticide poisoning and water-borne diseases, such as schistosomiasis. The second point is that management of environmental impacts presents special problems because of the difficulty of establishing property rights in air and water, and in some cases land (where it is held in common). In the absence of property rights to these resources, markets are not established for allocating them among users and charging for the services they render, for example as dumps for effluents of agricultural production.

Consequently the costs of the services--environmental costs--are not borne by those who impose them but by others who subsequently use or are exposed to the air, water or land. The disassociation between the imposer and bearer of these costs creates issues of economic efficiency and social equity which in most instances require some form of public intervention.

Chapter 5 considers the environmental impacts likely to result over the next several decades from efforts of the developing countries to increase food production. There are no comprehensive quantitative data relevant to this issue and relatively little data of any kind. The fragmentary evidence available suggests, however, that environmental damage from agriculture already is high in the developing countries. Given the scale of effort needed to meet anticipated demands for food, these damages could rise substantially higher. Our judgment is that erosion and various problems associated with irrigation, particularly salinity and water-borne diseases, are likely to be more important than problems of fertilizer and pesticide pollution. While the technical knowledge for coping with these more serious problems is reasonably well developed, the institutional, economic, and social obstacles to bringing this knowledge to bear are formidable. The erosion problem in many hill regions, for example, reflects a combination of high population pressure, limited access to less erodible land, existence of communal land holdings, and limited opportunities for non-agricultural employment. Under these circumstances it is difficult to reduce pressure on the land or to induce farmers to adopt erosion control techniques.

Chapter 6 considers projections to 1985 by the U.S. Department of Agriculture of crop production in the United States under baseline

and high-demand assumptions, and the quantities of land, fertilizer and pesticides likely to be employed. This chapter, therefore, addresses the same issues with respect to the United States as chapter 3 does for developing countries.

Much of chapter 6 is concerned with analysis of the effects of prices and productivities of inputs and of government policies on farmer choices among technologies. While the analysis is inconclusive, it indicates that for a given level of production the behavior of productivity is crucial in determining the quantities of resources used. This is not a surprising result, but it is particularly important because there now is great uncertainty about the future course of productivity. From the early to mid-1970s agricultural productivity in the United States grew hardly at all, in contrast to two previous decades of rapid increase, and yields per acre of major crops declined or were only marginally above previous peaks. While bad weather and expansion of crops onto marginal lands accounted for some, perhaps much, of this behavior, there is evidence also that the potential for productivity growth of the technologies on which U.S. farmers have long relied is now much more limited than it was a decade ago.

We have not attempted to determine the relative importance of these factors affecting productivity and yields. Our analysis shows, however, that the projections of harvested land are particularly sensitive to assumptions about these factors, with pesticide projections less sensitive and projections of fertilizer the least sensitive of all. Explanation of the recent behavior of yields and productivity is a major focus of research on U.S. agriculture now underway at RFF.

Chapter 7 is focused on the likely environmental impacts in the United States of the levels of land, fertilizer and pesticide use projected in

chapter 6 and on some of the policy issues likely to arise in dealing with these impacts. Some attention is given also to salinity associated with irrigation, although we have made no projections of irrigation water or irrigated land. Chapter 7, therefore, treats the same issues for the United States as chapter 5 does for the developing countries.

We note the great difficulty of determining the damages resulting from erosion, fertilizer and pesticide pollution and salinity, but conclude that erosion is likely to be perceived as the most serious of the environmental problems, particularly if yield growth is slow and the high demand situation prevails. In these circumstances there would be great pressure to convert to crops tens of millions of hectares of land now in pasture, forest or range. Much of this land would be subject to substantially higher rates of erosion than land now in crops, unless appropriate tillage or erosion control measures are taken.

While we conclude that the erosion problem may be more important in the United States than fertilizer or pesticide pollution or salinity, we note great uncertainties about the environmental damages done by these materials, particularly nitrogen fertilizer, organophosphorous insecticides and herbicides. The chief uncertainty about nitrogen fertilizers concerns possible damage to the ozone shield by various oxides of nitrogen. There is evidence that this damage may become large over the next several decades, but the evidence is inconclusive. Moreover some students of the problem argue that the damage, if any, is a function of the total amount of fixed nitrogen worldwide, not just that embodied in chemical fertilizers. In this case management of the problem would require international cooperation and could present exceptional technical and political difficulties. For example, developing substitutes for nitrogen

fertilizer such as biological nitrogen fixation in grains would not be a feasible technical solution. Even if a technical solution were found, effective implementation might founder on differing perceptions among countries of the costs and benefits of control.

In the United States there is a marked trend toward substitution of non-persistent organophosphorous insecticides for persistent organochlorines and toward greater use of herbicides. There is a presumption that these trends will have favorable effects on the environment since persistence complicates the problem of pesticide management and herbicides are considered benign to most forms of animal life. We do in fact regard these trends as favorable, but we stress that this conclusion is tentative. It is well established that most organophosphorous compounds are non-persistent but it is not established that they are free of long-term ill effects. Both field experience and experimental work with these materials are insufficient for judgment on this score. With respect to herbicides it seems clear that they have little harmful effect on most higher forms of animal life, but there is some evidence that they may damage lower trophic levels. If this is true then the cumulative damage to ecological systems could in time be serious.

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_____. 197_. Foreign Agriculture Circular: Grains. FG 6-77 May 2, 1977.

Chapter 2

FOOD CONSUMPTION AND THE GROWING FOOD GAP IN THE DEVELOPING NATIONS

Food Consumption: Recent Trends and Regional Differences

The world food situation has been and continues to be dominated by two ominous trends--the addition of millions annually to the hundreds of millions of people already suffering from malnutrition and threatened with famine, and the increasing dependence of developing areas on food imports to sustain their generally inadequate levels of food consumption. These trends were sometimes overlooked in the past because of the increase in average per capita food production in both the developing and the developed regions in the past two decades.[1] Increases in per capita food consumption, however, have been closely associated with rising incomes, and not all groups have participated in the average income increases. Indeed, there is little reason to believe that food consumption among the world's poorest 15 to 20 percent improved at all during the past two decades, yet their number increased by about 200 million. While the growth of food output exceeded the growth of population for the developing nations as a group from 1952-72, the opposite was true in thirty-four developing countries. In about two-thirds of the developing countries the increase in production lagged behind the increase in demand.[2]

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[1]Since historical data on food consumption in Communist Asia are not available, references to the world and developing nations in this section exclude Communist Asia. The following section on food demand projections does include these areas which, in accordance with the FAO usage, are referred to as the Asian centrally planned economies.

[2]U.N. Food and Agriculture Organization, The State of Food and Agriculture 1974, pp. 93-94.

Globally, average per capita food consumption during the 1950s and 1960s fluctuated little from a slightly rising trend reflecting increasing affluence.[3] Behind this steady growth in average per capita consumption are wide differences in the quantity and quality of diets among and within countries. In countries with the productive or import capacity to provide good average diets, national policies presumably could eliminate malnutrition and hunger; this study does not examine intracountry differences in food consumption. National redistribution policies, however, are not sufficient in the poorer countries: additional food is required. The caloric deficit among poor countries in the mid-1970s has been estimated at about 25 million tons of grain, which is equivalent to about 16 percent of their 1974 production.[4]

FAO data and analysis indicate wide quantitative and qualitative differences in average per capita food consumption among various areas. Quantitatively, the developed areas consumed an average of 45 percent more calories per person than the developing areas. Qualitatively, the diet differences are apparent in the number of calories obtained from vegetables, fruits, meat, eggs, fish, and milk. The developed areas consumed an average of 852 calories per day or 28 percent from these sources, compared to only 220 calories or 10 percent of average food consumption in the less developed areas.[5]

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[3]This stability can be attributed to two underlying factors. First, short-run fluctuations in production generally were countered by changes in the stocks of harvested crops, livestock, and root crops with wide flexibility in harvesting time. Second, excess productive capacity in the major exporting countries made the long-run food supply very elastic.

[4]Buzki and Goering, A Perspective on the Foodgrain Situation, p. 14.

[5]An FAO analysis of the relations between average national incomes and diets concludes: (1) the proportion of calories supplied by fats rises from about 15 percent in countries with average incomes of $100, to 30 percent with incomes of $600, to 40 percent with incomes of $2,600; (2) this increase is due to greater consumption of meat, milk, fish, and separated fats

(continued)

Intercountry differences in calorie consumption understate the differences in resource requirements of food consumed in low-and high-income countries. The direct consumption of grains common to low-income diets provides a much more efficient source of calories than grain-fed animal products. For example, in 1973/74 the average conversion rate in the United States was 5.5 pounds of grain for each pound of beef on a retail equivalent basis, yet cereals and beef provide roughly the same number of calories per pound. The efficiency of cereals relative to beef is not so great but still substantial when compared in terms of protein value. The net protein utilization, which "is an index of digestibility of protein and the biologic value of the amino acid mixture absorbed from the intestine," is 56 for cereals and 82 for beef on a scale with eggs equivalent to 100.[6]

Population growth was the primary factor behind the 2.8 percent average annual rise in food consumption from 1954 to 1973. Three-fourths of the increase in the world's population outside Communist Asia over these two decades occurred in the developing nations, increasing their percentage of the total from 56 to 62. With annual population growth now in excess of 2.5 percent in the developing market economies and less than 1 percent in developed nations, the lower-income nations now account for 83 percent of the world's population

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(footnote 5 continued)
(oils, butter, margarine, shortenings, and lard) and reduced consumption of unseparated vegetable fats and oils (in cereals, nuts, and oilseeds); (3) the proportion of total calories supplied by carbohydrates declines from about 75 percent in countries with average incomes of $100, to 60 percent with incomes of $600, to 50 percent with incomes of $2,600; (4) while the proportion of calories supplied by total protein does not change with income, the proportion supplied by animal protein rises from about 2 to 8 percent as incomes rise from $100 to $2,600 per capita. The results are reported in U.N. Food and Agriculture Organization, Provisional Indicative World Plan, vol. 2, chapter 13. This summary of the FAO conclusions regarding the relations between average national incomes and diets is from Willett, "Food Needs," pp. 45-46.

[6]President's Science Advisory Committee, The World Food Problem, vol. 2, pp. 50-51.

increases outside Communist Asia and 86 percent including those Communist countries.[7] The developing nations, however, have not accounted for a comparable percentage of the increase in food production, and it appears that they have fallen further behind the developed nations in per capita consumption as well.

The combination of production, trade, and population data indicate changing consumption patterns between the developed and less developed nations. Based on a linear trend from 1954 to 1973 food production grew at average annual rates of 3.0 percent in the low-income nations and at 2.7 percent in the higher-income nations. However, the much higher population growth reduced per capita increases to only 0.4 percent per year in the developing areas, compared to 1.5 percent in the developed areas.[8] The production data can be adjusted by international trade data to more closely reflect consumption. Yet, despite major changes in international grain trade over this period, trade had little impact on the annual growth of food consumption for the developing nations as a group. Net imports of grain (excluding rice) into the developing market nations grew from an annual average of 6 million metric tons in 1950/51-1951/52, to 12 in 1960/61-1961/62, to 18 in 1970/71/1971/72, and to 32 in 1974/75 (see table 1).[9] When the increase in grain imports is added to the 3 percent increase in

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[7]U.S. Department of Agriculture, The World Food Situation, pp. 12-16.

[8]U.S. Department of Agriculture, The World Food Situation, p. 12.

[9]Rice would add about 3 to 4 million metric tons to the annual net grain imports of the developing market countries from 1972/73 to 1974/75.

Table 1. Average Annual Net Grain Exports and Imports, Selected Areas[a]

(million metric tons)

	1950/1 to 1951/2	1955/6 to 1956/7	1960/1 to 1961/2	1965/6 to 1966/7	1970/1 to 1971/2	1972/3	1973/4	1974/5
Market Economies								
A. Net exporters								
1. Developed								
United States	15.1	18.0	30.9	44.5	38.1	70.2	71.2	62.4
Canada	9.8	9.5	10.0	15.6	18.4	18.8	13.1	12.8
Australia and New Zealand	3.7	3.6	6.5	6.8	11.7	5.6	9.2	11.8
South Africa	-0.1	0.9	1.4	0.1	1.9	0.5	4.1	4.0
Subtotal	28.5	32.0	48.8	67.0	70.1	95.1	97.6	91.0
2. Developing								
Argentina	2.9	4.8	5.2	10.6	8.5	10.7	10.3	8.6
Thailand	b	b	0.5	1.2	1.9	1.1	2.2	2.0
Subtotal	2.9	4.8	5.7	11.8	10.4	11.8	12.5	10.6
B. Net importers								
1. Developed								
Western Europe	-21.6	-22.1	-26.2	-28.1	-23.3	-17.6	-22.3	-16.8
Japan	-2.4	-3.6	-4.9	-10.0	-15.2	-17.5	-19.4	-18.1
Israel	-0.3	-0.5	-0.7	-0.8	-1.2	-1.2	-1.3	-1.3
Subtotal	-24.3	-26.2	-31.8	-38.9	-39.7	-36.3	-43.0	-36.2

(continued)

Table 1. (continued)

	1950/1 to 1951/2	1955/6 to 1956/7	1960/1 to 1961/2	1965/6 to 1966/7	1970/1 to 1971/2	1972/3	1973/4	1974/5
2. Developing								
Latin America[c]	-3.3	-3.2	-4.9	-4.8	-6.2	-10.8	-9.9	-9.8
Asia[d]	-5.0	-3.7	-9.3	-14.9	-14.9	-13.0	-17.3	-21.8
Africa	-0.9	-0.6	-3.6	-5.8	-7.1	-8.3	-10.6	-11.3
Subtotal	-9.2	-7.5	-17.8	-25.5	-28.2	-32.1	-37.8	-42.9
Centrally Planned Economies								
USSR	3.4	4.0	7.2	-0.9	3.2	-19.6	-5.3	-0.5
Eastern Europe	-1.9	-5.0	-5.9	-6.5	-8.4	-7.4	-4.9	-7.5
China	0.5	0.1	-4.3	-5.4	-3.4	-6.1	-7.7	-6.3
Others[e]	--	-0.1	-0.3	-0.6	-0.8	-0.7	-1.0	-0.5
Subtotal	2.0	-1.0	-3.3	-13.4	-9.4	-33.8	-18.9	-14.8

Source: The figures up to 1970/1 to 1971/2 were calculated from data in U.S. Department of Agriculture, World Grain Trade Statistics, tables 1 and 25. The more recent data are from the USDA Foreign Agricultural Service computer printouts of data based on a May 20, 1975, report date.

[a] Includes wheat, corn, sorghum, barley, oats, and rye. Rice is not included.

[b] Less than 50,000 metric tons.

[c] Excluding Argentina.

[d] Excluding Thailand.

[e] Includes Mongolia, North Korea, and North Vietnam. Data for 1950/51 and 1951/52 are not available.

food production, the growth of total food availability in the developing nations was about 3.1 percent per annum, or a per capita increase of only 0.5 percent per annum.[10] These growth rates of food availability are not significantly altered by considering the trade of other food products.

From 1972 to 1975 the problems of malnutrition and famine were amplified by changes in the food supply situation. Widespread crop failures in 1972 and 1974 reduced world food reserves to the lowest levels in memory. Mass famine threatened the poorest regions of Africa and Asia, while hunger spread to millions unable to maintain former diets because of high prices, poor harvests, and lack of food reserves. Early prospects for record harvests during 1975 fueled hopes of easing the short-run global food crisis, and international agricultural prices started declining sharply in November 1974. These expectations did not materialize, however, as crop failures in and large grain purchases by the USSR started pushing international grain prices back up in June 1975. These price increases were reversed in the final quarter of 1975 due to expectations for a record world grain harvest in 1976. Record production was realized in 1976 and by early 1977 grain farmers were being pressured by declining grain prices and rising stocks. However, stocks were still not sufficient to cover simultaneous production failures in several of the major grain-producing regions.

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[10]This conclusion assumes that cereals currently account for 50 percent of total food consumption in developing areas. According to FAO data, cereals actually accounted for about 45 percent by weight of total food demand in the developing market countries from 1969-71. The importance of cereals in food consumption would be higher than 45 percent since the food demand total includes both feed grains and products such as meat, eggs, and milk. See United Nations, Assessment, pp. 80-81. Net grain imports by the developing areas from 1972/73 to 1974/75 were about 9 percent of total grain production in these countries. See U.S. Department of Agriculture, World Agricultural Situation, table 4, p. 24.

Food Demand Projections

The current world food situation poses a short-term humanitarian challenge to the international community to transfer more food to the world's hungry, as well as a technical challenge to increase food production and reserves to restore the capacity to counter local production shortfalls. Over the longer term, the challenge will be to satisfy the rising demand for food. Population growth ensures large future increases in food demand concentrated in the poorer nations. Moreover, current low consumption levels suggest that consumption must grow faster than population if malnutrition and hunger are not to spread. This section examines the magnitude of the global and regional food demand levels to the year 2000.

The food demand projections of the FAO are used as a starting point for examining the dimensions of future food demand. The most recent FAO food demand projections start from a 1970 base, calculated as an average of 1969 to 1971, and assume relative food prices will remain constant at around the 1970 level throughout the period.[11] These projections, which are made independently of any supply considerations, are based primarily on historical population and income trends. While the FAO projections are for 1985 and 1990, we have calculated the implications of continuing the growth trends projected between 1985 and 1990 for another decade. Although none of these projections are intended to be forecasts, the relevance of historical trends to future demand levels undoubtedly becomes more remote as the time horizon is extended. Nevertheless, the projections of these trends combined with an analysis of their sensitivity to alternative growth

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[11] The FAO food demand projections used in this chapter are presented in United Nations, Assessment, especially pp. 51-54, 78-87, and 101-106.

of population and per capita consumption is useful for indicating the magnitude of the future agricultural production challenge.

Aggregate food demand projections for the world and the broad regional classifications of developed, developing market, Asian centrally planned, and all developing countries are presented in table 2. These regions, which are referred to frequently in this study, are defined in a note of table 2. The aggregate food demand projections as well as the cereal demand projections presented in table 3 are based on the assumptions of "medium" population and "trend" income growth. The population levels and growth rates associated with these projections are presented in table 4. The "trend" income assumptions are based on actual growth performances from 1960 to 1973 with some adjustments of historical rates to reflect the expected adverse effects of high energy costs on some oil-importing areas and the improved growth prospects of oil-exporting countries.

These aggregate food demand projections suggest that world demand will rise 44 percent by 1985 and 112 percent by 2000 in comparison to the 1970 level. In spite of the projected decline in the growth rates for both the developed and developing regions after 1985, the average annual growth of world demand rises from 2.4 percent over the 1970-1985 period to 2.6 percent over the 1985-2000 period. This increase reflects the rising relative importance of the less developed countries which have considerably higher growth rates and account for most of the change in world food demand. Indeed, if we use cereal consumption in 1970 (see table 3) as representative of the relative importance of the various regions in total food demand in the initial period, the developing countries account for 71 percent of the total growth in world food demand from 1970 to 1985 and 78 percent from

Table 2. Aggregate Food Demand Projections to 1985 and 2000 (with medium population and trend income assumptions)

Regions[a]	Annual growth rates (percent)		Demand levels (indices with 1970=100)	
	1970-1985[b]	1985-2000[c]	1985[b]	2000[c]
Developed countries	1.5	1.4	125	155
Developing market economies	3.6	3.6	170	289
Asian centrally planned economies	3.1	2.7	158	236
All developing countries	3.4	3.3	166	270
World	2.4	2.6	144	212

[a]The regional breakdown corresponds to that adopted by the FAO. Thirty-three countries, including the USSR and Eastern Europe are classified as developed. The People's Republic of China, North Korea, Mongolia, and North Vietnam are classified as "Asian centrally planned economies" and 125 countries are classified as "developing market economies." These latter two groups combined comprise "all developing countries." The annex table in United Nations, Assessment, pp. 51-54, lists the countries included in the "developed" and "developing" categories.

[b]The 1985 figures are taken from United Nations, Assessment, table 14, p. 79.

[c]The food demand growth rates for the 1985-2000 period assume population will continue to grow at the 1985-1990 rates which are calculated from the UN medium population assumptions presented in table 4. Per capita food demand is assumed to grow at 0.6 percent per year in developed countries, 0.9 percent in developing market economies, and 1.5 percent in the Asian centrally planned economies, which are the "trend" rates presented in United Nations, Assessment, table 14, p. 79. The demand levels for 2000 and growth rates from 1985-2000 for "all developing countries" and the world are calculated as weighted averages. The weights, which are the percentages of total cereal consumption in 1970 in each region, were calculated from data in Assessment, table 17, p. 84. The breakdown of projected world cereal demand in 1970 is 51 percent in developed countries, 32 percent in developing market economies, and 17 percent in Asian centrally planned economies.

Table 3. Demand for Cereals with FAO "Trend" Growth Assumptions

	Actual consumption[a] (million metric tons)*	Projected demand			Annual rates of growth (percent)	
	1970	1985[a]	1990[a]	2000[b]	1970-1985	1985-1990
Developed countries	617 (60.2)*	796 (65.6)	847 (66.8)	954	1.7	1.2
Developing market economies	386 (9.2)	629 (12.5)	738 (13.8)	1,012	3.3	3.2
Asian centrally planned economies	204 (7.5)	300 (16.2)	325 (18.8)	385	2.6	1.7
All developing countries	590 (8.5)	929 (13.7)	1,063 (15.4)	1,397	3.1	2.8
World	1,207 (35.0)	1,725 (37.7)	1,910 (38.2)	2,351	2.4	2.1

*The numbers in parentheses indicate the demand for feed as a percentage of each region's total demand for cereals.

[a]The figures for 1970, 1985, and 1990 are from United Nations, Assessment, table 17, p. 84. Rice is treated on a paddy basis.

[b]The figures for 2000 assume that the annual growth rates from 1985-1990 will continue until 2000.

Table 4. Population: 1970 and Projections to 1985 and 2000

	1970 actual[a] (millions)	Projections 1985[a]	Projections 2000[b]	Rates of growth 1970-1985[a] (percent per year)	Rates of growth 1985-2000[b] (percent per year)
Developed countries	1,072	1,227	1,383	0.9	0.8
Developing market economies	1,755	2,623	3,914	2.7	2.7
Asian centrally planned economies	794	1,008	1,208	1.6	1.2
All developing countries	2,549	3,631	5,122	2.4	2.3
World	3,621	4,858	6,505	2.0	2.0

[a]The 1970 and 1985 data as well as the 1990 data used in calculating the 1985-2000 annual growth rates are from United Nations, Assessment, p. 102. The United Nations 1974 population data are the source of the figures.

[b]The figures for the year 2000 are calculated from data in ibid. under the assumption the population in the developed, developing market, and Asian centrally planned regions will continue to grow at the 1985-1990 rates for another decade.

1985 to 2000. Table 3 indicates that the developing nations account for two-thirds of the 518 million ton increase in annual world cereal demand from 1970 to 1985 and three-fourths of the 626 million metric ton increase from 1985 to 2000.

The developing market economies comprise the most dynamic component of the growing world food demand; these countries will account for a sharply increasing portion of world demand for all major food groups. For example, while the developing market countries accounted for as much as half of the 1970 world consumption in only one commodity group (pulses, nuts, and oilseeds) of the eleven categories used by the FAO, these countries account for more than 50 percent of the increase in world demand from 1985 to 2000 for every group except meat and eggs. Furthermore, while the developing market countries accounted for only 32 percent of the world's 1970 cereal consumption, they are projected to account for 47 percent of the increase in world cereal demand between 1970 and 1985 and 61 percent of the increase between 1985 and 2000.[12]

The annual percentage increases in per capita food demand implied by the FAO "trend" income assumptions are 0.6 for the developed nations, 0.9 for the developing market economies, and 1.5 for the Asian centrally planned economies. The projections to 2000 assume no change in these regional per capita growth rates. Under these assumptions average per capita food demand in all developing nations would grow at 1 percent per annum. It is

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[12] Feed grains account for more than 98 percent of the projected increase in cereal demand in the developed nations between 1970 and 1985 compared to 23 percent in the developing nations. Data for food demand by major commodity group for 1969-1971 and projections for 1985 and 1990 are from United Nations, Assessment, pp. 80-81. The demand projections for 2000 assume demand will continue to grow for another decade at the 1985-1990 rate implied by the FAO data.

interesting to note, however, that the worldwide annual increase in per capita food demand would be only 0.4 percent from 1970 to 1985 and 0.6 percent from 1985 to 2000. The growth of average world food demand at a lower rate than the per capita growth in any of the three component regions is due to the much higher population growth rates in those areas with lower average food demands.

The above projections are based on specific assumptions regarding future population increases and the factors determining per capita food demand. While we believe the assumptions underlying these projections are reasonable, substantial uncertainty is involved. And as we move out in time, deviations from these assumptions could cause increasingly large errors in the projections. The uncertainties regarding future food demand are particularly great for the developing nations due to their higher income elasticities of demand for food and the greater uncertainties regarding population and income growth. Equally defensible assumptions regarding the combination of changes in population and per capita demand might generate substantially different food demand levels for the developing countries. The differences between such alternative projections and those of table 2 might reach 10 percent by 1985 and 20 percent by 2000.[13]

Rather than attempting to justify the specific assumptions underlying the projections of table 2 or working with a range of future food consumption

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[13]The aggregate food demand projections for the developing nations presented in table 2 assume average annual growth rates of 2.4 percent from 1970 to 1985 and 2.3 percent from 1985 to 2000 for population and 1 percent over both periods for per capita demand. To demonstrate the impact of a more extreme combination of assumptions on the projected aggregate food demand of the developing areas, low and high demand variants were developed. The low projection assumes average annual population growth rates of 2.24 percent from 1970-1985 and 1.66 percent from 1985-2000 and a per capita demand growth of 0.2 percent per annum. These population growth rates are based on Frejka's "projection 3" adjusted to include Argentina, Chile, and Uruguay as developing nations. See Frejka, The Future of Population Growth, pp. 105 and 240. These growth rates assume that the net reproduction rate will fall (continued)

possibilities, we prefer to view the "medium" projections as minimum objectives for future food increases. The desirability of achieving food consumption increases in the developing nations of at least the magnitude implied in these medium projections is argued in the Report of the Panel on the World Food Supply by the President's Science Advisory Committee. In projecting food demand the Panel started with an evaluation of food requirements and current consumption and then estimated the consumption increases from 1965 to 1985 necessary to achieve food consumption goals. Attainment of these goals requires an average increase in per capita food consumption of about 1.6 percent per year over these twenty years.[14] Even under optimistic assumptions regarding population growth, the aggregate food demand projections of the medium growth variant for 1985 and 2000 imply average annual per

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(footnote 13 continued)
to 1 between 2000 and 2005, an achievement that would require maximum efforts to develop family planning programs. The high projection assumes average annual population growth rates of 2.52 percent from 1970-1985 and 2.40 from 1985-2000 and a per capita demand growth of 1.4 percent per annum. These population projections, which are based on Frejka's "projection 5," assume that the net reproduction rate will fall to 1 between 2040 and 2045 and represents Frejka's expected outcome if fertility control efforts continue at the levels of the early 1970s. With 1970 aggregate food demand in the developing nations set equal to 100, the projections with the low and high variants would be 144 and 178 as of 1985 and 190 and 312 as of 2000. In comparison to the medium projections of table 2, the high variant represents increases of 7 and 14 percent and the low variant represents decreases of 13 and 30 percent as of 1985 and 2000 respectively. These high and low variants might be interpreted as upper and lower limits to conceivable food demand. They are clearly not intended to suggest likely combinations of per capita demand and population growth since a high population growth would probably depress the growth of per capita demand. The demand projections of likely combinations of per capita demand and population growth would fall within a smaller range. Readily defensible assumptions might result in food demand projections for the developing nations ranging about 7 percent above and 10 percent below the 1985 "medium" projections. The percentage deviations might be about twice as great for the 2000 projections.

[14] President's Science Advisory Committee, The World Food Problem. In particular, see vol. 1, pp. 21-22 and vol. 2, chap. 1.

capita gains in the developing nations below the goals of the President's Panel.[15]

The Growing Food Gap in the Developing Nations

Unless the growth of food production is accelerated in the developing areas, output will fall increasingly short of the "medium" food demand projections presented in table 2.[16] For example, continuation of 1961-1973

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[15] Frejka, The Future of Population Growth, pp. 105 and 240 estimates that maximum efforts to develop family planning programs would reduce the net reproduction rate to 1 between the years 2000 and 2005 in the developing areas. Under these population growth assumptions and the FAO's medium projected food demand growth rates, the average annual per capita increases in food demand in the developing nations would be only 1.16 percent from 1970 to 1985, 1.64 percent from 1985 and 2000 and about 1.4 percent from 1970 to 2000.

[16] There are strong interdependencies among the underlying supply and demand conditions affecting aggregate food consumption. While the amount and distribution of income and population size are the primary determinants of aggregate food demand, these variables are influenced by agricultural supply conditions. With farming the largest employer and food the largest component of most family budgets, food production and prices are important determinants of real income among the rural and urban poor and of overall economic development in many regions of the world. Population growth, the other principal component of rising food demand, is also influenced by the economic security and opportunities associated with agricultural prosperity. Famine, of course, would curb population growth. However, malnutrition, listlessness, low productivity, and economic insecurity, which are by-products of poverty, are generally associated with high reproductive rates and an expansion and intensification of poverty.

Agriculture has a key role to play in eliminating this vicious poverty circle. Not only does it produce the food essential for a healthy and productive world population, but agriculture is the sector with the greatest potential for productively employing the poorly trained rural masses during the foreseeable future. Understanding the interactions among the supply and demand factors and the commonality among such societal objectives as improved diets, health, and economic productivity is essential for meeting long-run food needs. Elimination of hunger and malnutrition requires a solution to demographic problems and elimination of abject poverty. These interrelationships, however, are not the subject of this study.

Table 5. Food Demand and Production Projections for Developing Regions

	Growth rates (percent per annum)			Projected levels (indices with 1970=100)			
	Food demand		Production	1985		2000	
	1970-1985[a]	1985-2000[b]	1961-1973[c]	Demand	Production[d]	Demand	Production[d]
Africa	3.8	4.0	2.5	176	145	318	210
Far East	3.4	3.3	2.4	166	143	272	204
Latin America	3.6	3.5	2.9	170	152	285	233
Near East	4.0	4.0	3.1	180	157	327	248
Developing market economies	3.6	3.6	2.6	170	146	289	215
Asian centrally planned economies	3.1	2.7	2.6	158	146	236	215

[a]These data are from United Nations, Assessment, table 14, p. 79.

[b]These growth rates are calculated under the assumptions explained in note c of table 2.

[c]These are exponential trend growth rates. The data are from table 19, p. 87, and the method of calculation is explained on pp. 106-107 of United Nations, Assessment.

[d]The production projections assume a continuation of the 1961-1973 growth rates.

production growth rates would leave output lagging behind these demand projections by 1 percent per annum for all the developing countries combined (see table 5). The regional gaps would vary from 1.3 percent per annum for Africa to 0.7 percent for Latin America. The food gap in Africa would grow so rapidly under these assumptions that within thirty years the increase in the food gap would exceed the initial year level of food demand.

Data in table 1 illustrate the increasing dependence of the developing areas on cereal imports.[17] Net cereal imports (excluding rice) by the developing market nations increased fivefold during the third quarter of this century. If Argentina and Thailand, the only major net grain exporters among the developing nations, are excluded from the list of developing nations, net grain imports (excluding rice) in 1974/75 totaled 42.9 million metric tons for the developing market nations and 6.8 million for the Asian centrally planned economies.

Table 6 projects grain demand and production to 1985 and 2000 for the developing market regions under the assumptions of "medium" demand growth and a continuation of 1961-1973 growth rates of production.[18] The gap between annual grain demand and production would reach 72 million tons by 1985 and 171 million tons by 2000 under these assumptions.

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[17]Gaps between the consumption and production of food are commonly filled by cereal shipments, and discussions of the food gap generally focus on the cereal gap. It should be noted, however, that while the developing countries as a group are net food importers, they are net exporters of all agricultural products.

[18]Obviously, the size of the grain gaps in table 6 are determined by the growth assumptions for demand and production. As noted above we prefer to view the demand projections as minimum objectives, and the production trends are intended only to demonstrate the implications of recent historical growth rates. The historical rates are dependent on the period chosen, and by using the 1961-1973 period we have conformed to the FAO selection. The FAO concludes that these "production trends may be a little conservative as far as climatic influences are concerned" in that four of the twelve years were poor crop years. See United Nations, Assessment, p. 107.

Table 6. Projections of the Grain Gap in Developing Market Nations

(million metric tons)

	1985[a]			2000[b]		
	Demand	Production	Gap	Demand	Production	Gap
Wheat	140	121	-19	223	219	-4
Rice (milled)[c]	183	157	-26	285	221	-64
Coarse grains	214	187	-27	362	259	-103
All cereals	537	465	-72	870	699	-171

[a]The 1985 projections are from United Nations, Assessment, table 21, p. 91. The demand projections are based on the FAO "medium" projection and production is assumed to grow at the trend rates from 1961 to 1973. As is explained in note c, rice has been converted from a paddy to a milled basis.

[b]The year 2000 demand and production projections assume that the historical rates for each crop and region implied in the United Nations projections for 1985 and 1990 will continue until 2000.

[c]FAO figures, which treat rice on a paddy basis, have been converted to a milled basis under the assumption that 3 units of paddy convert to 2 units of milled rice. The projected trade gaps for rice on a paddy basis are 39 million metric tons in 1985 and 95 million in 2000. The gaps for all cereals would be 85 million metric tons in 1985 and 202 million in 2000. With the FAO figures converted to treat rice on a milled basis, their 1985 projection is virtually identical to the USDA projection of 71.6 million metric tons of cereals for the trade gap of the developing market economies under the alternative characterized as the "high world import demand situation." See U.S. Department of Agriculture, The World Food Situation, pp. 35 and 37.

While these projections are useful for illustrating the magnitude of the overall food balance problem, this level of aggregation is not very useful for evaluating the potential for and problems of filling the gap through either imports or increased production. Since development strategies are formulated by individual countries, an in-depth analysis of these issues requires national data. For our purposes it is perhaps sufficient to distinguish between net grain importers and exporters as well as between countries with and without the means to finance large commercial grain imports. Table 7 presents cereal deficit projections to 1985/86 by the International Food Policy Research Institute (IFPRI) which provide this level of disaggregation.

After adjustments are made for differences in the date and the crops and countries included,[19] the net deficit of 82.6 million tons (table 7) under IFPRI's high growth assumption is not significantly different than the 72 million ton deficit (table 6) which uses FAO assumptions. The similarities stem primarily from the use of virtually identical assumptions regarding population growth rates and the dominance of population growth in the growth of food demand. The income elasticities of demand are also generally the same for the two studies. However, IFPRI's average projected increase in per capita Gross National Product is 3.0 percent for the high and 1.7 percent for the low growth variants compared to the FAO "medium" projection of 3.5 percent per annum. In both cases the underlying food production projections

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[19] For example, the IFPRI deficit is reduced to 72.6 million tons when the projection horizon is reduced by six months, Taiwan is excluded, and pulses are deleted from India's deficit--all of which are required to make the IFPRI and FAO assumptions consistent. The differences are discussed in International Food Policy Research Institute, Meeting Food Needs, p. 12.

are extensions of historical trends; IFPRI uses the 1960-74 period and FAO uses the 1961-73 period.[20]

IFPRI's projections indicate that Brazil and Pakistan will join Argentina and Thailand as net grain exporters by 1985/86. The combined exports of these four countries are projected at 29.0 and 25.8 million metric tons under the low and high growth variants respectively. With these net exporters deleted, the projected net grain imports of the developing market economies range from 94.4 to 108.3 million metric tons. While nearly one-third of these imports would be by countries with high foreign exchange capacity, net imports by countries lacking good foreign exchange earning prospects range from 64.8 to 73.4 million metric tons. And more than two-thirds of these projected net imports are by countries with incomes under $200 per capita.

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[20] The Asian centrally planned economies are not included in tables 6 and 7 because of the particularly great uncertainties regarding their historical and future food production and consumption levels. Food production over the past ten to fifteen years has grown considerably faster than population in China. Thus, projection of recent trends shows China and, therefore, the Asian centrally planned economies as significant net grain exporters in 1985. While the role of planning on both the production and consumption sides makes such an outcome possible, it is not considered likely. IFPRI assumes China's agricultural policies will lead towards self-sufficiency within the Asian centrally planned economies as a group, and USDA projections call for net grain imports of 4.1 to 6.7 million metric tons in 1985 by these Asian countries. See U.S. Department of Agriculture, World Food Situation, p. 35.

Table 7. Projected Cereal Deficits in Developing Market Economies, 1985-1986

(million tons)

	High growth	Low growth
Net Importers	-108.3	-94.4
Low income (under $200 per capita)		
Asia	-34.4	-29.4
North Africa and Middle East	-2.4	-2.3
Sub-Sahara Africa	-12.9	-11.7
	-49.7	-43.4
Middle income ($200+ per capita)		
North Africa and Middle East	-8.7	-8.3
Sub-Sahara Africa	-2.0	-2.0
Latin America	-13.0	-11.1
	-23.7	-21.4
High income (high foreign exchange capacity)		
Asia	-20.4	-16.8
North Africa and Middle East (OPEC)	-11.4	-10.7
Latin America	-3.1	-2.1
	-34.9	-29.6
Net Exporters	+25.8	+29.0
Argentina	+15.7	+16.1
Brazil	+1.1	+3.4
Pakistan	+3.7	+3.9
Thailand	+5.3	+5.6
Net cereal deficit: all developing market economies*	-82.6	-65.5

Source: International Food Policy Research Institute, Meeting Food Needs in the Developing World: The Location and Magnitude of the Task in the Next Decade, Report No. 1, February 1976.

*These do not add due to rounding. Some more recent but unofficial projections by IFPRI staff suggest that these cereal deficits may be overstated. The principal change involves about a 15 million ton reduction in Asian cereal consumption due to the use of lower income elasticities of demand for meat.

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Chapter 3

RESOURCE AND TECHNOLOGICAL FACTORS IN ACCELERATING AGRICULTURAL PRODUCTION IN THE DEVELOPING AREAS

Meeting the rising food needs of the developing countries, particularly of the poorest (per capita incomes under $200), is one of the most urgent and difficult global challenges of the next and subsequent decades. The magnitude of these food gaps and the limited capacity of these countries to earn the foreign exchange required to fill the gaps with commercial cereal imports suggest the need to accelerate agricultural development in the developing areas. This chapter examines the resource and technological factors affecting the potential for and the costs of agricultural expansion in the developing areas.

Land and Water Potential

Assessments of land potential by three major research groups have concluded that agricultural land potential far exceeds the amount of land currently under crops both worldwide and in the developing nations as a group. Surveys by the President's Science Advisory Committee and the FAO have estimated the land that can be potentially used for agriculture, and a more recent survey by the USDA attempts to measure cropping potential.

The 1967 Report of the Panel on the World Food Supply by the President's Science Advisory Committee concluded that: "The area of potentially arable land on the earth is much larger than anyone has previously supposed, being 24 percent of the total ice-free area and considerably more than twice the land that has been cultivated at some time during the

last few decades. It is more than three times the area actually harvested in any given year." The Committee's estimates place 64 percent of the world's 3.3 billion potentially arable hectares in Africa, Asia excluding the USSR, and South America, and conclude that only 37 percent of the potentially arable land in these developing areas has been cultivated at some point during recent decades. Moreover, the committee estimated the world's maximum gross cropped area, which takes into account the possibilities for double and triple cropping, to be about 6.6 billion hectares or approximately twice the potentially arable land.[1]

FAO estimates in the late 1960s concluded that the developing market nations had 1,145 million hectares suitable for crop production. Although the FAO estimates of arable land potential are substantially below those of the President's Science Advisory Committee, the FAC still concluded that as of 1962 only 45 percent of the potentially arable land had been used for annual or permanent crops, temporary grass, fodder, or fallow.[2]

USDA estimates place the current and potential agricultural land in the developing market nations at 1,648 million hectares, of which 530 million or 32 percent are in use.[3] In these estimates, land yielding two crops in a year is counted twice while fallowed land is not counted as being under cultivation.

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[1]President's Science Advisory Committee, The World Food Problem vol. 2, pp. 407 and 434.

[2]Food and Agriculture Organization, Provisional Indicative World Plan p. 49.

[3]Data provided by Patrick O'Brian of the Economic Research Service, U.S. Department of Agriculture.

Water, of course, is as essential to agriculture as land. Insufficient and unreliable water receipts either preclude the successful cultivation of land or restrict the productive potential of all other agricultural inputs. The availability and reliability of the water supply are the most important factors in both the feasibility of multiple cropping and the adoption of inputs such as fertilizer and high-yielding seed varieties which have made possible dramatic increases in yields.

The global water situation is similar to that for land; large quantities of potential irrigation water remain unused, and there are extensive opportunities for more efficient use of water in both irrigated and dryland farming. Over two-thirds of the world's fresh water flows unused into the oceans, large ground water stocks could be tapped for agriculture, and the technology exists to desalinate sea water. Yet water places greater restrictions on agricultural growth than land in many areas of the world, and there are large tracts of potentially fertile land that are likely to remain barren because of the absence of sufficient low-cost water. Successful agriculture requires bringing both water and land resources together at competitive costs. Since the estimates of potentially arable land discussed earlier take into account the availability of water, these estimates reflect the limits to agricultural expansion imposed by the availability of both primary resources. All these estimates suggest, and it is widely accepted, that the world as a whole and the LDCs as a group have never utilized as much as 50 percent of their potential agricultural

land when potential is vaguely conceived to refer to land possessing some minimum soil qualities and accessibility to water supplies.[4]

The availability of large unused land and water resources globally and in the developing nations as a group provides little insight as to the problems and the ability of individual countries or the developing countries together to solve their food problems. Although an expanded food trade among the developing nations is certainly possible and perhaps warranted by the large differences in the availability of land and water resources relative to food demand, abundant unused land and water resources in South America or Central Africa will not solve the food problem of South Asia. Moreover, these resources will help South America and Central Africa only to the extent that they are brought into production at competitive costs. The following section looks at some of the regional differences in and the problems stemming from the relative availability of resources in relation to population; later sections examine the cost issues.

Regional Resources and Development Constraints

Since land and generally water are not economically transferable among countries, an efficient global agricultural development would allocate readily transportable resources among the land and water resources offering the highest returns after allowance for transfer costs. There are wide differences in the agricultural factor proportions available to countries, and a more efficient global use of these resources requires greater international movements of such inputs as labor, capital, and fertilizer than currently occur.

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[4]The Environmental Fund in a Declaration on Population and Food expressed a contrary but unsubstantiated view that "We have reached, or nearly reached, the limit of the world's ability to feed even our present numbers adequately." See The Washington Post, October 25, 1974.

While freer international movements of capital and fertilizer are realistic and important objectives for the international community, the obstacles to large-scale population movements among countries are becoming increasingly intractable. International migrations of a magnitude which would significantly alter the pressures on countries with high population densities are not realistic. Countries with large populations relative to their natural resources are and, barring calamity, will remain a dominant feature of the global food situation.

The available data are inadequate for a detailed examination of the variations in the relative use and availability of productive factors among countries. Estimates of agricultural land use and potential are based on very weak data and, for reasons discussed in the next section, the estimates are somewhat arbitrary and dependent on narrow assumptions regarding technology and cost constraints. Nevertheless, some consideration of the range of different factor proportions is important for understanding the prospects and options for agricultural growth in the developing world. And, in spite of their deficiencies, the data consistently illustrate important differences in the agricultural land situations among developing areas. Tables 8 and 9 illustrate national and regional differences in the use and availability of land and labor resources within the developing areas. Table 8 presents FAO estimates of land and labor use as of 1961-63 and 1985 for twenty-four developing nations and four major developing regions. With the exception of the Far East, there are wide differences among the land-labor ratios of the countries in each region. For example, the 1961-63 ratios for Africa south of the Sahara range from 9.3 hectares per worker in Niger to 1.2 in Zaire, for the Near East and Northwest Africa they range from 9.5 in Syria to 0.6 in Egypt, and for South America they range from 16.8 in Argentina to

Table 8. Agricultural Land and Labor Use in Selected Developing Countries

	Land use[a] (million hectares)		Population economically active in agriculture (millions)		Land use per person economically active in agriculture (hectares per person)	
	1961-63	1985	1961-63	1985	1961-63	1985
Africa, South of Sahara						
Chad	6.8	7.1	1.0	1.6	6.5	4.5
Ethiopia	14.0	19.8	8.7	11.3	1.6	1.7
Ghana	8.0	8.0	1.7	2.4	4.6	3.3
Kenya	8.1	9.8	3.0	4.7	2.7	2.1
Niger	8.8	9.6	0.9	1.6	9.3	5.9
Nigeria	31.8	31.8	13.6	18.7	2.3	1.7
Tanzania	14.0	17.4	4.4	6.4	3.2	2.7
Zaire	7.2	14.0	5.8	7.1	1.2	2.0
Regional total	151.8	189.3	60.0	81.2	2.5	2.3
Far East						
India	161.5	164.4	141.1	169.3	1.1	1.0
Pakistan and Bangladesh	25.5	28.7	25.3	39.1	1.0	0.7
Philippines	7.9	10.1	8.3	12.2	0.9	0.8
Thailand	8.6	11.1	14.9	16.7	0.7	0.7
Regional total	209.8	222.4	195.5	248.9	1.1	0.9
Near East and N.W. Africa						
Afghanistan	9.0	11.1	4.4	6.1	2.1	1.8
Egypt	2.6	3.2	4.5	6.6	0.6	0.5
Iran	16.8	19.6	3.5	4.0	4.8	4.9
Iraq	6.7	6.3	1.0	1.3	6.7	4.7
Sudan	7.1	10.1	3.5	5.6	2.0	1.8
Syria	6.6	6.9	0.7	1.0	9.5	7.0
Regional total	50.7	59.2	19.3	26.4	2.6	2.2

(continued)

Table 8. (continued)

	Land use[a] (million hectares)		Population economically active in agriculture (millions)		Land use per person economically active in agriculture (hectares per person)	
	1961-63	1985	1961-63	1985	1961-63	1985
South America						
Argentina	25.7	41.3	1.5	1.0	16.8	42.8
Brazil	48.8	58.6	12.0	13.1	4.1	4.5
Chile	4.5	4.7	0.8	0.8	5.9	6.2
Colombia	5.1	7.1	2.5	3.5	2.0	2.0
Peru	2.6	3.7	1.7	2.1	1.5	1.8
Venezuela	5.2	5.6	0.9	0.8	6.1	6.6
Regional total	101.0	133.7	21.5	24.2	4.7	5.5
Total of above regions	513.3	604.6	296.3	380.8	1.7	1.6

Source: Food and Agriculture Organization, State of Food and Agriculture, 1973, p. 141.

[a]Land use in this table refers to what the FAO calls "arable land." This includes all areas which are used from time to time or full-time to grow crops as well as areas under temporary grass, fodder, and fallow.

Table 9. Cropping, Cropping Potential, and Population in Selected Areas, Early 1970s

	Cropping potential[a] (million hectares)	Land under crops[a]	Land use as percent of potential	1973 population[b] (millions)	Cropping potential per capita (hectares	Cropping per capita per person)
Developing market countries						
East Asia	70.6	29.6	42	230.5	0.31	0.13
Indonesia	55.8	17.9	32	124.6	0.45	0.14
High income	4.8	4.4	92	54.1	0.09	0.08
Low income	9.9	7.2	73	51.8	0.19	0.14
Southeast Asia	46.9	25.0	53	99.6	0.47	0.25
Thailand	11.8	10.3	87	39.8	0.30	0.26
Other	35.1	14.8	42	59.8	0.59	0.25
South Asia	221.0	178.8	81	756.9	0.29	0.24
India	176.0	149.5	85	574.2	0.31	0.26
Other	45.1	29.3	65	182.7	0.25	0.16
North Africa and Middle East	120.6	63.6	53	205.9	0.59	0.31
High income	76.4	21.7	28	74.1	1.03	0.29
Low income	44.2	42.0	95	131.8	0.34	0.32
Central Africa	522.4	110.8	21	195.3	2.67	0.57
East Africa	200.7	23.3	12	61.8	3.25	0.38
South America	411.6	68.8	17	204.6	2.01	0.34
Argentina	42.7	19.5	46	24.3	1.76	0.80
Brazil	249.9	29.2	12	101.7	2.46	0.29
Venezuela	26.0	2.5	9	11.3	2.30	0.22
Other	93.0	17.7	19	67.3	1.38	0.26

(continued)

Table 9. (continued)

	Cropping potential[a] (million hectares)	Land under crops[a] (million hectares)	Land use as percent of potential	1973 population[b] (millions)	Cropping potential per capita (hectares per person)	Cropping per capita (hectares per person)
Mexico	35.0	24.2	69	54.3	0.64	0.45
Central America	19.4	5.9	30	32.6	0.59	0.18
Total	1,648.1	530.0	32	1,841.5	0.89	0.29
China	110.3	95.0	86	799.6	0.14	0.12
Total including China	1,758.4	625.0	36	2,641.1	0.67	0.24

[a]The data were provided by Patrick O'Brian of the Economic Research Service, U.S. Department of Agriculture. The regional breakdowns are those used by the USDA.

[b]The population estimates were calculated from the mid-1973 UN estimates reported in United Nations, "Population and Vital Statistics Report".

1.5 in Peru. In contrast, the amount of land per agricultural worker in the Far East is low in all countries and averages only 1.1 hectares for the region.

In addition to harvested areas, the land use estimates used in table 8 include areas under temporary grass, fodder, and fallow, which require little to no labor input. The FAO's estimates of cropping intensities, defined as the areas harvested as percentages of the total land in use, are 100 percent for the Far East, 42 percent for Africa south of the Sahara, 56 percent for the Near East and Northwest Africa, and 54 percent for Latin America.[5] Consequently, for the Far East the figures in table 8 provide a reasonable approximation of the average labor used for lands harvested at least once during the year. For the other regions, however, average labor use per hectare on harvested areas is considerably higher than those suggested in table 8, but still generally below the levels for the Far East.

Table 9 relates USDA estimates of land use and potential to 1973 population levels. In contrast to the FAO data, the USDA land estimates focus on actual and potential cropping; a hectare which is used for or has the potential for multiple cropping appears as more than 1 hectare in the estimates. Unfortunately the available data do not permit identical regional breakdowns for both tables 8 and 9. Nevertheless, the two tables are mutually supportive in regard to the general conclusions as to regional land use and potential. Table 9 indicates that 83 percent of the unutilized

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[5]The cropping intensities are from Food and Agriculture Organization, Provisional Indicative World Plan vol. 1, table 3, p. 44. The references to the FAO land use estimates in the text and in table 8 are called arable areas in the FAO documents.

agricultural land potential of the developing market countries lies in the regions of South America and East and Central Africa, while only 9 percent is in East, Southeast, and South Asia. Even with China added to this list of developing countries, the unutilized agricultural land potential of these Asian countries is still less than 11 percent of the total for developing countries. Yet these Asian countries account for 71 percent of the total population of the developing areas. When current cropping is related to cropping potential, the utilization rates are 81 percent for South Asia and 86 percent for China, compared to only 12 percent for East Africa, 17 percent for South America, and 21 percent for Central Africa. The per capita agricultural land potential in 1973 averaged only 0.31 hectares for all the developing market countries in East, Southeast, and South Asia and the Asian average drops to 0.24 hectares with China included. In comparison, there is about ten times as much potential agricultural land per person in South America and East and Central Africa.

The 1985 projections of land and labor use presented in table 8 reflect FAO assessments of a variety of factors affecting future development, especially the possibilities for and the costs of expanding the land base and the probable size of the agricultural labor force. South America is the only region where the land-labor ratio is expected to rise during the period from 1961-63 to 1985. This rise results from a 32 percent anticipated increase in land use, concentrated in Argentina and Brazil, and a 13 percent increase in agricultural labor in the region. In Africa and the Near East land use is expected to rise 25 and 17 percent, respectively, but the agricultural labor forces in both regions are expected to increase by more than 35 percent over the same period. Agriculture in the Far East also is expected to

become more labor intensive with projected increases of 27 percent in employment and only 6 percent in land use. In India, which accounts for about three-fourths of the agricultural land and labor included in the Far East data, land use is projected to rise by only 1.8 percent over these twenty-three years despite a projected 20 percent increase in agricultural labor and an initial high agricultural labor intensity. In Pakistan and Bangladesh the FAO projects increases of 13 percent in total land use and 55 percent in farm labor.

Based on the FAO's projected growth of agricultural land and labor use, it is apparent that average yields of both these productive factors must increase substantially for agricultural production to keep pace with demand in the developing areas. Table 10 presents for selected areas the annual yield increases required for production to increase commensurate with IFPRI's cereal demand projections, given the land and labor use projections of table 8.[6] While the relatively land abundant countries of Africa and Latin America have considerable leeway regarding the land and labor proportions associated with their agricultural development, the alternatives in a densely populated country such as India are narrowly

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[6]The implied yield increases are obviously crude approximations since they are calculated as the residuals of the annual growth of the IFPRI cereal demand projections from 1969-71 to 1985/86 and the FAO agricultural land and labor use projections from 1961-63 to 1985. However, there are two principal reasons for expecting that the bias resulting from the use of these inconsistent data does not overstate the yield increases required for food production to keep pace with demand. First, according to the FAO projections for the 1970 to 1985 period, aggregate food demand will grow faster than cereal demand in the developing market economies; i.e., 3.6 percent versus 3.3 percent per annum (see tables 2 and 3). Second, the rate of increase in land and labor use is probably declining over time in most of the countries presented in table 10 since the quantity and quality of virgin lands are declining and land-labor ratios are declining to levels where the marginal productivity of labor is very low in the most densely populated areas.

Table 10. Land and Labor Yield Increases Required for Production to Keep Pace With Cereal Demand: Selected Developing Areas

(percent per year)

	Land		Labor	
	High growth	Low growth	High growth	Low growth
India	2.3	2.2	1.6	1.5
Pakistan and Bangladesh	2.6	2.6	1.2	1.2
Philippines	2.4	2.3	1.8	1.6
Thailand	2.2	2.1	1.8	1.7
Egypt	2.1	2.0	1.3	1.2
Brazil	2.0	1.7	2.4	2.1
Nigeria	3.8	3.6	2.4	2.2
Africa, South of Sahara	2.1	2.0	1.8	1.7

Assumptions:

Growth rates of agricultural land and labor use are those implied for the 1961-1963 to 1985 period by the data in table 8. The demand growth rates are those implied for the 1969-1971 to 1985/1986 period by the cereal consumption projections of the International Food Policy Research Institute, Meeting Food Needs, pp. 31-40. The yield increases are calculated as the residuals required to increase production commensurate with demand with the assumed growth of land and labor.

Data availability determined the countries and the region included in this table.

circumscribed by the scarcity of unused land and the social need to increase agricultural employment. With land use growing only at 0.1 percent per year, India's agricultural development will depend almost entirely on its ability to increase land yields. The data in table 10 suggest that average land yields must be increased about 25 percent and labor yields about 17 percent in one decade for production to keep pace with demand in India. Although land yields will normally rise as more labor is applied, in the absence of technological change diminishing marginal productivity is the general rule; the output derived from additional labor is apt to be particularly low when there is only about 1 hectare per worker as in India.

The Increasing Cost Hypothesis

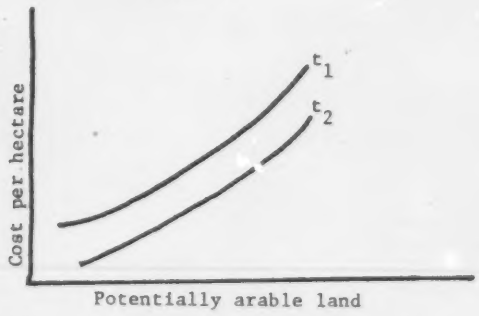
While areas favored with large unused land and water resources have a broad range of development options available, this does not mean that their agriculture will expand rapidly with no substantial increase in unit costs. Nor does the lack of large unused land and water resources imply slow growth and rising costs. Unfortunately, global estimates of resource availability of the sort reviewed above shed little light on the likely costs of or desirable patterns for agricultural development in various countries or regions.

In view of the problems and uncertainties involved, it is hardly surprising that the various efforts to survey global agricultural land potentials have never specified how these estimates might vary under different assumptions regarding costs and technology or the precise costs and technologies consistent with a given estimate of land potentials. Nevertheless, quantification of the land and water resources with agricultural potential or the agricultural potential of given quantities of land and water are not very meaningful without reference to the underlying assumptions

regarding costs and technology. With no cost constraints, the technology either exists or could probably be developed to bring almost any land under cultivation. Certainly the FAO's estimate that only 26 percent of the total land area in the developing countries is suitable for crops would rise sharply in the absence of cost constraints.[7] For example, large areas of desert, which have been excluded from estimates of potentially arable land, could be cultivated with desalinated sea water. Although technically this is already a possible means of expanding the agricultural land base, it is not economically feasible under current energy and product prices and technologies. Efforts to determine land potential become equally questionable when technological assumptions are relaxed. To continue with the preceding example, it is possible that technological advances could make the irrigation of deserts with sea water a profitable undertaking even with current input and product prices.

It is reasonable to expect that for a given technology the supply of potentially arable land would rise as the allowable cost of developing the land is increased. See figure 1. Moreover, as new technologies are developed, the position of this supply curve should fall (from t_1 to t_2),

Figure 1



[7]U.N. Food and Agriculture Organization, Provisional Indicative World Plan vol. 1, p. 49.

implying that more land would be potentially arable at a given cost level. Although there would be some limit to the potentially arable land, this limit would be much closer to the total quantity of land on earth than indicated by the above mentioned surveys and the limit might even increase as a result of new technology. Any such limits, however, have little relevance for understanding the world food situation over the next several decades or for many years beyond that. Of much greater interest are the costs of incorporating new lands and the impact of technology on these costs.

Table 11 presents the FAO's estimates of feasible land and water development objectives up to 1985 for various developing regions as well as their estimates of the average cost of renovating or developing a hectare in each region. These estimates represent what the FAO calls "physical possibilities" for land and water development since they are made under the assumptions that the technical and administrative requirements for development somehow will be met. There is no indication, however, how changes in these crucial assumptions might affect the cost estimates.

Some important differences in regional development directions are suggested by these FAO objectives and cost estimates. For example, the percentages of the total investment in land and water development devoted to irrigation are 39 in Latin America, 66 in Africa, 78 in the Far East, and 85 in the Near East. The Far East accounts for about 50 percent of the total land and water investment in the developing areas, and although the estimated average costs of developing new arable lands in the Far East are well above the comparable costs for the other regions, the estimated costs of irrigating new areas and renovating or improving existing irrigated areas are lower in the Far East than in the other regions.

Table 11. FAO Objectives and Cost Estimates of Land and Water Development to 1985 in Developing Areas

	Renovation and improvement of existing irrigation areas		New irrigation		Development of new arable land	
	Hectares (million)	Cost per hectare (1974 dollars)	Hectares (million)	Cost per hectare (1974 dollars)	Hectares (million)	Cost per hectare (1974 dollars)
Far East	28	$418	15	$1,467	24	$396
Near East	12	558	3	2,467	10	250
Africa	1	500	1	2,400	34	44
Latin America	5	420	4	1,550	85	151

Source: United Nations, The World Food Problem, pp. 66-67.

The admittedly imprecise FAO cost estimates summarized in table 11 are not likely to allay the debate regarding the future world food situation which stems in large part from uncertainty regarding the costs of increasing agricultural production either by bringing more land under cultivation or by increasing yields on currently cropped areas. Pessimism regarding the future world food situation stems largely from a belief that increased output will entail sharply higher unit costs. A proponent of this view is Lester Brown. A book by Brown with Erik Eckholm argues that:[8]

> On the supply side, three sets of factors are beginning to affect efforts to augment world food output as rapidly as is necessary. Serious technological constraints are limiting the rapid expansion of food, particularly beef and soybeans; all four of the major resources used to produce food--land, water, energy, and fertilizer--are now in tight supply; and in a growing number of situations the pressures of growing demand for food are beginning to undermine the ecology of major food-producing systems.

Moveover, they feel these factors represent fundamental shifts suggesting that the era of

> ...chronic excess capacity, surplus stocks, and low food prices...is being replaced by a period of more or less chronic scarcity and higher prices, with little if any land held out of production.

In regard to the role of the primary resources on expanding agricultural production, Brown and Eckholm conclude that:

> Most of the good cropland in the world is already under cultivation. Additional opportunities for expanding the world's cultivated area exist, but they are mainly limited to the interior of Latin America and parts of sub-Saharan Africa. And even in these regions, the cost of food produced on the new land may be much higher than that of food grown in cultivated areas.

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[8]Brown and Eckholm, By Bread Alone, pp. 6-8.

Despite these land limitations, they conclude that:

> ...the principal constraint on efforts to expand world food supplies during the final years of this century may well be water rather than land. In many regions of the world, fertile agricultural land is still available--provided that water can be found to make it productive. But most of the rivers that lend themselves to damming and to irrigation have already been developed. The expansion of irrigated area is slowing as the more attractive sites are exhausted...

Objections to the increasing cost hypothesis are supported by the historical experience of agricultural growth in the United States and the possibilities of a comparable experience in the developing nations. Referring to the U.S. experience to the late 1950s, Barnett and Morse concluded:

> ...that the increasing scarcity hypothesis was invalid for agriculture for the period 1870 to the present. According to the hypothesis, scarity and its increase would force the unit cost of agricultural output to rise. But not only did unit cost of net output fail to rise during this period, it actually experienced a downward trend--whether cost is measured in labor plus capital or in labor alone. [illegible] the beginning to the end of the period, unit cost of [illegible]icultural products declined by more than half, if cost [illegible]asured in labor plus capital.[9]

Of [illegible]rance for assessing the future agricultural situation is the following more general conclusion of the Barnett and Morse study:

> That man will face a series of particular scarcities as the result of growth is a foregone conclusion; that these will impose general scarcity--increasing cost--is not a legitimate corollary. The twentieth century's discovery of the uniformity of energy and matter has increased the possibilities of substitution to an unimaginable degree, and place at man's disposal an indefinitely large number of alternatives from which to choose. To suppose that these alternatives must eventually become so restricted, relative to man's wants, that increasing cost will be inescapable, is not justified by the evidence. An absolute limit to the possibilities

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[9] Barnett and Morse, Scarcity and Growth, pp. 167-168.

> of escape may exist, but it cannot be defined or specified. The finite limits of the globe, so real in their unqueried simplicity, lose definition under examination. [10]

The relevance of the increasing cost hypothesis will depend on the ability of the developing nations to develop and incorporate new techniques both for increasing yields on currently cultivated areas and for bringing new areas under cultivation. Tropical areas are particularly important as agriculture spreads to virgin areas both because most of the untapped land and water resources are in tropical areas and because the technologies which have proven successful in the developing areas have little direct relevance to the problems of tropical areas. Furthermore, the tropics are very diverse and will require site specific technologies. The pessimism expressed by Brown and Eckholm will prove prophetic if agriculture in the developing nations expands primarily along traditional lines. Indeed, this option is no longer open to most Asian countries. Efforts to expand along traditional lines would soon encounter rising costs; higher costs would make it difficult to sustain former agricultural production growth rates and would virtually eliminate the hopes for accelerating these rates. These hopes rest upon man's proven ability to overcome the limitations to numerous resource constraints with new technologies and to capture the potential for large increases in agricultural yields through the adaptation and adoption of existing technologies. Thus technological advance provides the general means for accelerating agricultural growth and forestalling the advent of increasing agricultural costs. Success, however, is by no means assured. Examples of man's application of science and technology to overcome the limitations of resource constraints have been concentrated in but not limited to the developed nations. Furthermore, the technologies underlying advanced

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[10] Barnett and Morse, Scarcity and Growth, pp. 244-245.

agricultural systems are dependent on fuel energy inputs which have become much more costly in recent years and have never been readily available to farmers in most developing areas.

An Historical Look at Technological Change

The scientific principles and concepts underlying the dramatic transformation of agriculture in the developed world have only recently been applied in a major way to agriculture in the developing world. There are three underlying explanations for the still very limited impact of agricultural science on farmers in developing areas. First, in a physical sense recommended technologies tend to be area specific such that a technological package developed for specific climatic, soil, and water conditions can seldom be successfully transplanted from one region to another without substantial modification. Second, in an economic sense the types of technologies that are beneficial under conditions such as well-established product and factor markets and relatively expensive labor and cheap capital which are characteristic of most developed areas may not be beneficial under the conditions encountered by most farmers in the developing areas. And third, the developing countries have been slow to develop the research institutions and personnel capable of effectively bringing scientific principles to bear on indigenous problems.

The first concerted effort to apply established scientific principles to agriculture in the developing areas prompted what is commonly referred to as the Green Revolution. The origins go back to the development of improved wheat varieties in Mexico in the mid-1940s; the adoption of improved varieties reached 50 percent of Mexican wheat lands by 1953 and 90 percent by 1960. However, it was not until the mid-1960s, when use of new wheat,

rice, and corn varieties was spreading rapidly in many developing areas, that the term Green Revolution emerged. Indeed, the successes and resulting hopes were so great during the mid- to late-1960s that "revolution" quickly became a widely accepted term. By 1972/73 nearly 33 million hectares in Africa and Asia were planted to high-yielding wheat or rice varieties, and the average yields on these lands were about double for wheat and 10 to 20 percent higher for rice than the average yields of traditional varieties planted on lands of comparable quality.[11]

The Green Revolution technologies were primarily the product of the plant breeding programs initiated in the 1940s for wheat and corn at Chapingo, Mexico, and at a later date for rice at Los Baños in the Philippines. The multidisciplinary teams of these research centers developed recommended packages of water, fertilizer, and pesticides to accompany the new seed varieties. These seeds and recommended inputs were continually tested by other research stations located in similar ecological areas. Generally the most promising varieties were not suited for other locations because of the presence of new pests and climatic variables, and the process of rebreeding and retesting continued until new seeds and input packages had been proven suitable to a particular location. It took nearly two decades of such breeding and testing before the new rice and wheat seeds were considered acceptable for widespread adoption in parts of India and Pakistan.

In 1962 the rice breeding center at Los Baños was organized into an international center, and in 1968 the center at Chapingo underwent a similar reorganization. Since that time, eight additional research institutes

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[11] Dana Dalrymple, "The Green Revolution," pp. 2, 4, 30-31.

have been added to the international network. The field research of these centers now covers all major food crops in the developing areas as well as problems of livestock productivity. The funding for and intellectual stimulus behind the international research centers came primarily from the Rockefeller and Ford foundations. Since 1971 the funding and activities of these international centers has been coordinated by the Consultative Group on International Agricultural Research (CGIAR), which is jointly sponsored by the International Bank for Reconstruction and Development (IBRD), the Food and Agriculture Organization of the United Nations (FAO), and the United Nations Development Programme (UNDP), and receives financial support from about sixty institutions.

In addition to undertaking field research designed to increase yields of the principal crops in their respective regions, the international research institutes have provided centers for collecting and preserving genetic varieties from all over the world and for disseminating innovations worldwide. The effectiveness of the highly skilled and scarce human resources required to develop major technical breakthroughs undoubtedly has been enhanced by the use of international centers. Nevertheless, since biological innovations tend to be area specific, global effectiveness of such research is dependent on the capacity of national research stations to test and adapt the high-yielding varieties and input packages to local conditions. The international centers work closely with national research groups to facilitate the dissemination and local adaptation of innovations. Nevertheless, while some national research stations have been successful, local research efforts are still the weak link in developing improved agricultural technologies throughout the developing world.

The euphoria that accompanied the rapid spread of the high-yielding varieties in the last half of the 1960s has waned in recent years as events have focused attention on some of the limitations of this "revolution." Events in India during the first half of the 1970s were particularly important in influencing the general outlook. Adoption of the high-yielding wheat and rice varieties was most rapid in India, and in 1974/75 India accounted for 61 percent of the high-yielding wheat and 51 percent of the high-yielding rice planted in Asia and the Near East.[12] Increases in wheat production were particularly impressive as the land under high-yielding wheat in India rose to 6.5 million hectares in 1970/71 and average yields increased by 7.5 percent per annum between 1967/68 and 1970/71. The growth of wheat yields, however, leveled off nationally and actually declined in some of India's principal producing areas during the first half of the 1970s.[13] More recently grain production and yields in India have improved over the performance of the first part of this decade. Led by a record wheat harvest, India's total grain production reached record levels in 1976/77.[14]

The fact that the introduction of the high-yielding wheat and rice varieties was not the panacea for rural poverty in the developing nations or the world's food problem should not detract from either the very real gains derived from this development or the potential benefits of additional agricultural research within the developing areas. Although

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[12] Dana Dalrymple, Development and Spread of High-Yielding Varieties, pp. 110-113.

[13] Wheat yields started declining in Haryana after 1969/70 and in Punjab after 1970/71, the centers of India's wheat revolution. After four straight years of declining yields, 1973/74 average wheat yields in Haryana were only 73 percent of their 1969/70 level. Government of India, Estimates of Area and Production of Principal Crops, pp. 67-69.

[14] U.S. Department of Agriculture, Foreign Agriculture Circular-Grains.

there is some concern regarding the ability of the developed agricultural areas to maintain prior rates of yield increases,[15] the developing areas have only recently begun exploiting the potential benefits of agricultural research. Slowdowns in both the adoption rates of and the yield increases from these high-yielding varieties do not indicate that the developing areas are approaching the limits of the potential benefits of agricultural science. They do suggest, however, that if the "revolution" is not to be stalled by resource constraints and increasing costs, greater emphasis must be given to the availability and use of complementary inputs, and research must provide a continual flow of new technologies relevant to a broad spectrum of farmers in the developing countries. The generation of such a flow of technology will require both a substantial increase in the resources devoted to research and a careful planning of research priorities.

Some of the limitations of the new seed varieties that have received increasing attention in recent years stem from their dependence on the presence of a whole package of complementary inputs, including water, fertilizer, chemicals for plant protection, and improved farm management practices, which are not readily available throughout the developing world. In areas with conditions favorable to the adoption of the new varieties, especially in regard to water availability, use of the new seeds spread rapidly. For farmers lacking either excellent initial growing conditions in terms of soil fertility and water availability or access to the capital required to improve these conditions, the new technologies offer little or

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[15] The National Research Council, Productive Agriculture and a Quality Environment, p. 88, suggests two basic reasons for caution in projecting future trends in agricultural yields in the United States: some curves relating output to input in agriculture are beginning to level off, and the goals of technology may shift from increasing yields to improving environmental quality. The prospects for productivity growth in American agriculture are discussed in detail in chapter 6 of this report.

no advantage over traditional farming methods. And even on farms adopting the new seed varieties, the high costs or inaccessibility of some inputs, the absence of sufficient credit, and the increased financial risk stemming from the purchase of these inputs prompt many farmers to substantially modify their production packages from those recommended by the research stations.

Energy Use and Agricultural Growth

The technologies associated with high labor and land yields have required large increases in energy use in the form of chemical fertilizers, pesticides, and direct fuel consumption to move water or machines. This has been true regardless of whether the development has occurred in countries with high or low land:labor ratios or in developed or developing countries. In the absence of major new technological breakthroughs, agricultural development in the developing areas must follow the same energy-intensive pattern.

An examination of energy use in rural India by Roger Revelle illustrates both the low level of energy use and the dependence on noncommercial energy sources typical of rural developing areas.[16] For example, per capita energy consumption in rural India is just one-fiftieth of the use on U.S. farms, and while nearly all the farm energy in the United States is supplied from fossil fuels and hydroelectric power, in rural India more than 89 percent is supplied by local sources such as humans, animals, firewood, cattle dung, and crop residues. Revelle also projects the energy requirements of measures needed to make Indian agriculture competitive and sufficiently productive to meet food production needs in the coming decades. Agricultural expansion in India will depend largely on raising yields by increasing the use of

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[16]The data in this paragraph are from Revelle, "Energy Use in Rural India," Science, June 4, 1976.

fertilizer, irrigation, and double cropping. The major increases in energy needs will be for nitrogen fertilizer and pumping. The annual pumping associated with full development of irrigation potential would increase threefold the energy requirements of pumping, and application of 20 million tons of nitrogen fertilizer, which would be desirable for double cropping 100 million hectares, would have an energy requirement about 1.4 times total agricultural energy use in India as of 1971. Revelle suggests that a twofold increase in energy inputs combined with currently available but not generally adopted technologies, at least in principle, could increase India's agricultural output three- to fourfold. Thus, despite the much larger energy inputs, food production per unit of energy input from all sources actually could rise with agricultural development. However, neither India nor the developing areas in general can meet the requirement for more energy from traditional rural energy sources. For at least the next decade or so, most of the increase in energy will have to come from fossil fuels or, where the potential exists, hydroelectric power.

Given this situation, the price and availability of the fuel energy required for pumping, powering machines, and manufacturing chemical fertilizers and pesticides become critical to the agricultural development prospects of the developing nations. Most developing nations are dependent on foreign suppliers of fertilizers, pesticides, and fossil fuels. The potential problems associated with this dependence became harsh realities in the early 1970s. A more than fourfold increase in the price of oil between October 1973 and January 1974 had a devastating impact on the oil-importing, developing nations. The energy price rise seriously impaired their capacity to finance all imports and contributed to a sevenfold increase in international nitrogen fertilizer prices from 1971 to early 1974. High prices and shortages of many pesticides in 1974 also were due in part to their dependence on petroleum feedstocks and the diversion of scarce feedstocks to other uses.

The underlying causes of the rapid changes in the energy and nitrogen fertilizer situations between 1972 and 1974 were fundamentally different but interrelated because of the importance of energy in the production of nitrogen fertilizers. While higher prices for petroleum products contributed to the dramatic rise of nitrogen fertilizer prices between 1972 and 1974, the most important factor in the price rise was the limited productive capacity in relation to increased demand. This situation has been corrected, and since mid-1975 nitrogen fertilizer inventories have been high and prices well under one-half their 1974 average. In comparison, the high energy prices, which are the result of a producers' cartel, have been maintained. These high energy prices do not reflect limits in productive capacity or natural resource availability, but, unless the cartel collapses, energy prices are likely to remain high for many years.

Despite the high cost of fuel energy inputs, their adoption is profitable when combined with good farm management. Revelle's analysis of energy use in rural India supports this conclusion. For example, if India's agricultural energy inputs are tripled and all the additional energy is provided by petroleum products, the additional cost would be about $3.2 billion at 1976 world prices. In comparison, the additional output achievable with these energy inputs and good management would have a value of $35 billion or more at 1976 prices.[17]

The dependence of advanced agricultural systems on exhaustible energy resources raises questions about the long-run viability of these systems. While this dependence is likely to increase in the coming decades, science offers many promising opportunities for increasing yields without increasing

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[17] Revelle, "Energy Use in Rural India," p. 974.

the use of fuel energy resources. Some of the more promising opportunities are mentioned in the following section on research priorities.

Research Priorities

While the returns from agricultural research generally have been estimated to be very high relative to alternative investments,[18] several characteristics of this research increase the importance of carefully planning and allocating the very limited research capabilities of the developing areas. First, there are wide differences among the expected and potential returns of research projects depending both on the number of farmers that could benefit from the results and the type of scientific problems involved.[19] Second, there is likely to be a sizable minimum research effort required to develop a new and viable technology; consequently, the returns from a scattering of uncoordinated projects may prove very small. And third, there is a substantial time lag, often a decade or more, between the undertaking of a research effort and the initial benefits. The combination of these factors and the urgency of accelerating food production in the developing areas make it essential for a developing country to focus its research into relatively few carefully selected priority areas.

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[18] A United Nations document, The World Food Problem: Proposals for National and International Action, p. 88, states: "The outstanding conclusion which can be drawn regarding the application of agricultural technology in the world today is that research pays." Robert Evenson's claim "that 2 to 3 times as much growth can be obtained per dollar spent on research in developing countries than from any other form of investment," which is based on an investigation of several independent studies of the returns to research, is cited in support of the UN conclusion.

[19] According to United Nations, The World Food Problem: Proposals for National and International Action, p. 88, an important lesson from recent research experience is that "certain scientific problems both in the basic research activities and in the adaptive application of the results" have proved much easier to solve or control than others.

The most visible impact of agricultural research in the developing areas has been the development of the high-yielding grain varieties designed to maximize yields under very favorable growing conditions. Major advantages of this research approach have been its concentration on the world's most important food crops and the dramatic yield increases made possible by the package approach. Although the spread of such techniques may have slowed, the possibilities for increasing grain yields in the developing nations through the adoption of new varieties and complementary inputs are far from exhausted. The large gap between the average and demonstrated potential yields with the high-yielding grains suggest the possibilities of stimulating production by increasing the farmers' ability and incentives to use the new seeds and complementary inputs. Continued research on high-yielding grain varieties and input packages is also needed. Testing of new cereal varieties must continue indefinitely just to ensure that the varieties in use maintain a high degree of resistance to plant disease and pests. And testing in new locations is a prerequisite to a much wider geographic adoption of high-yielding grain varieties and input packages. Furthermore, research on the quality of these grains offers great promise for improving the nutrient value of the grains and, therefore, the diets of millions of the world's most poorly fed people. Major breakthroughs have already been made in developing high lysine corn and sorghum, and these protein-rich grains have helped cure children of the severe protein deficiency disease, kwashiorkor, and contributed to higher livestock yields.

The search for high-yielding varieties and input packages has been extended to other crops. Cereals are not the major food crops in many areas of Africa and South America and millions of farmers and consumers in

these areas are more likely to benefit from technological breakthroughs in crops such as peas, beans, and the root and tuber crops than from the new cereal varieties. The international research system has recognized the importance of such crops and field experiments on these crops have expanded rapidly since 1968. Despite the importance and potential benefits of such research, two factors suggest that the results of such research are not apt to be as dramatic worldwide as those of developing the new varieties of wheat, rice, and corn. First, the other crops are less important sources of food in the developing nations as a whole. And second, based on the research experience to date in both the developed and developing areas, the prospects for major breakthroughs in yields are less promising on most other crops. For example, a United Nations document prepared for the 1974 World Food Conference concluded:

> The food legumes, although after cereals the next most important source of protein in the diet of the lower income groups, offer less promising opportunities to research workers because of their susceptibility to numerous diseases and insects as well as their relatively low ceiling on yields. Both physical and morphological factors are involved. [20]

Agricultural research generally has focused on developing high-yielding seeds and input packages rather than varieties that might offer either moderate yields with fewer inputs or greater yield stability under a variety of conditions. The development of lower orders of technology and farm management practices such as crop rotation systems to improve the use of soil nutrients, use of indigenous inputs such as mulch and organic fertilizers, or new seeds and crops with greater resistance to drought might benefit millions of farmers who are not likely to benefit from research on seeds designed for

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[20] United Nations, The World Food Problem, p. 91.

very favorable growing conditions. Furthermore, such technologies would reduce the dependence of agricultural change on fuel intensive inputs.[21]

Livestock and fisheries management is another area which has received little attention by researchers in developing areas. While the knowledge exists to permit a sharp increase in productivity in these activities, little has been done to adapt this knowledge to the specific conditions encountered in developing areas. Aquaculture, the raising of aquatic species under some control of the organism and its environment, could provide an important source of protein in some areas. Its development, however, has been hampered by the lack of research.[22]

A research need of increasing importance is the development of soil management and cropping patterns to exploit the vast areas currently un- or underutilized because of the inability of the soils to support sustained cropping under current farming techniques. For example, techniques are inadequate for sustained cultivation of the humid tropics, and the environmental costs of slash and burn land development which is often employed in these regions may be great. The returns of research to cultivate such areas may prove particularly great in South America and Africa where large tracts of virgin lands with potentially favorable climates and topographies go unutilized because of technical difficulties. The potentially favorable

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[21] United Nations, The World Food Problem, argues the need for such research on rice. This report (p. 90) concludes "the rice varieties developed and released till now require considerable plant protection, controlled water application and a high level of management. Varieties, particularly of upland and of deep water rice, are needed which have a wider spectrum of resistance to pests and diseases and do not require such skilled management." The International Rice Research Institute (IRRI) is now working on these problems.

[22] The problems and prospects of aquaculture are discussed in C. P. Idyll, "Marine Aquaculture: Problems and Prospects."

aspects of tropical areas include abundant sunshine and often abundant water. To date, however, the climate of tropical areas has inhibited agricultural development through its impact on soil quality and the prevalence of diseases and pests afflicting plants, animals, and man.[23] Since solutions to these problems will generally be site specific and are not likely to emerge quickly, research efforts must be increased soon if these lands are to play a significant role in alleviating the world food problem within this century.

There are a number of more radical research lines with potentially important effects on food production and consumption in developing countries. One of these is research on triticale, a manmade grain species made from crossing wheat and rye. Triticale has demonstrated great potential as a high-protein and high-yielding grain capable of flourishing in marginal lands. Although the initial sterility of this hybrid has been overcome, the difficulty of producing reliable quality seed remains an obstacle to its widespread use.

Recent developments of other nonconventional food sources range from the processing of cotton seed into a high-protein flour to the synthesis of single-cell protein. While cotton seed had long been used for animal feed, it was not until the late 1960s that a substance toxic to humans could be removed without destroying most of the protein value of the seed. A high-protein cotton flour is now produced commercially in India and the United States. Single-cell protein, derived from the fermentation by yeasts, bacteria, algae, or fungi of materials such as carbon dioxide, oil,

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[23] Andrew Kamarck, The Tropics and Economic Development, emphasizes the impact of climate, especially the conditions in the humid tropics, on development.

and natural gas is a much more radical and as yet uncertain food source. Related research, which probably has greater short-run relevance to developing areas, is attempting to develop inexpensive vats and simple techniques for converting low-protein foods such as cassava into high-protein foods through fermentation. Research has also developed synthetic foods from materials such as coal, wood, and natural gas which have been used as animal feeds in the United States. While nonconventional food sources offer great potential for the long run, major unsolved problems regarding costs, consumer acceptance, scale of production, and nutritive qualities suggest that these foods are not apt to significantly alter the world food picture in the next decade or two.

Research has developed methods which enable farmers to improve the overall growing environments of plants. For example, protective coverings can increase the effective growing period or reduce crop losses from frost and hail, under some circumstances cloud seeding can increase rainfall or dissipate hail, and alternative irrigation systems such as trickle irrigation can both increase the efficiency of existing water supplies and increase crop yields by providing much greater control of soil humidity in the root zone. While these methods offer great potential for increasing effective yields per unit of land and water, their high costs and sophisticated managerial requirements currently limit their usefulness in most developing areas.

Two of the most promising research areas for increasing land and labor yields without larger fuel energy inputs seek to increase the photosynthetic efficiencies of plants and the abilities of plants to fix nitrogen in the soil.[24]

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[24]The following discussion of photosynthetic efficiency and nitrogen fixation draws extensively on S. H. Wittwer, "Maximum Production Capacity of Food Crops" and Gene Bylinsky, "A Scientific Effort to Boost Food Output."

Crop yields depend on the plant's ability to convert solar energy into plant material. Photosynthesis seldom converts more than 1 percent of the sunlight available during a growing season into plant growth, and in general only about 15 to 20 percent of the theoretical limit to the conversion of solar energy into plant material is achieved. Even the most efficient crops producing record yields now photosynthesize at only about half their potential. Science, however, may be able to improve upon this record. Major scientific breakthroughs during the 1950s in the understanding of the photosynthetic process have been followed by research designed to increase the photosynthetic efficiency of some plants. Scientists have demonstrated that the application of chemicals can improve photosynthetic efficiencies. For example, the use of carbon dioxide gas in greenhouses or dry ice in open fields have substantially increased yields of some crops. These techniques, however, are both expensive and energy intensive. Much more efficient application techniques must be developed for this technique to be commercially viable for crops in open fields. A more promising path for increasing crop yields per unit of fuel energy lies in genetic research to select plant varieties capable of more efficient photosynthesis.

Biological nitrogen fixation involves the extraction of nitrogen from the air by bacteria working in a symbiotic relationship with plants. This nitrogen becomes a nutrient for plants, reducing the need for chemical fertilizer. Legumes possess this ability to fix nitrogen in the soil, and research is attempting to increase the amount of nitrogen fixation and the yields of some legumes such as soybeans. Genetic research to transfer the nitrogen fixing ability to the principal grain crops may prove of much greater value to the developing areas. Since high grain yields are closely tied to the available nitrogen in the soil, inducing nitrogen fixation in the

grains could dramatically reduce the need for chemical fertilizers and, thereby, reduce the fuel energy requirements of food production.

A variety of other changes in farming practices or biological innovations might also enable farmers to increase yields without increasing their use of energy. Biological methods of controlling plant pests and genetic plant selection may partially replace pesticides, providing environmental as well as energy-saving benefits. Experiments suggest that a switch from conventional mechanized cultivation methods to minimum or zero tillage can reduce the fuel requirements of tractor use by 40 to 80 percent.[25] These energy savings, however, are at least in part offset by the increase in pesticides associated with minimum and zero till farming. Adoption of improved crop rotation schemes or composting can reduce the need for chemical fertilizers. And mulching with a wide variety of materials readily available in rural areas can reduce irrigation and cultivation requirements.

This discussion has not exhausted current or likely future research directions with potentially important impacts on the world food situation. We feel, however, the discussion has been sufficient to suggest that the results of such research could greatly alter the physical and economic constraints on the world food supply. Furthermore, it appears reasonable to conclude that the long-run returns from greatly enlarged agricultural research budgets, particularly in the developing countries themselves, are potentially very high if the funds are judiciously allocated. The limited supply of well-trained research personnel, however, is a major bottleneck to overcome before any major expansion of agricultural research can occur in the developing areas. The relative emphasis that should

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[25] Food and Agriculture Organization, The State of Food and Agriculture 1974, p. 30.

be given to the various research areas varies widely depending on the circumstances of each country. In general, however, the developing countries are best advised to concentrate their research efforts on increasing conventional food supplies by applying well-established research methods to produce technologies adapted to priority areas and crops. The potential returns from such an approach are enormous, and the prospects of success are high. On the other hand, high costs, sophisticated research techniques, and relatively long delays will be required before the newer, more radical research areas are likely to have a major impact on food production in developing areas. Moreover, the developing areas can expect to benefit from breakthroughs stemming from the basic agricultural research being undertaken by the developed countries and the international research institutes.[26]

Some Conclusions

The land and water resources of the developing nations are sufficient to support much higher levels of agricultural production with well-established, but as yet not widely adopted, technologies. Furthermore, well-funded, well-managed, and carefully planned agricultural research programs could greatly expand the production possibilities and produce benefits well in excess of research costs in the coming decades. In sum, the developing areas have the potential to increase agricultural production in step with a rapid increase in demand over the last quarter of this century.

Success in achieving these production increases, however, is not assured. The combination of long-term high energy costs and the high energy requirements of adopting advanced technologies and developing

[26]The U.S. National Academy of Sciences is scheduled to complete in 1977 a massive study of research needs related to the world food and nutrition problem. The study gives detailed consideration to the research issues that we necessarily must treat only at a general level.

new land and water resources will keep upward pressure on production costs. Current inefficiencies in allocating agricultural resources suggest the general means for countering the cost pressures arising from the energy-food connection. While examination of the factors influencing resource allocation is beyond the scope of this study, it is apparent that the problems of educating and motivating farmers, financing needed infrastructure investments, establishing reliable factor and product markets, and removing a myriad of institutional obstacles to an efficient allocation of natural, human, and financial resources are both formidable and central to accelerating agricultural production in the developing countries.

Since agricultural resources and their impact on production are not independent of the climate, our discussion has implicitly assumed that climatic conditions will not differ substantially from those of recent decades. Yet regions do experience long-run climatic changes, and, within the time perspective of this study, these changes can be of significance to a region's agriculture. Moreover, considerable publicity has been given to the views of several climatologists suggesting that the climate in some of the world's most important agricultural areas is becoming generally more detrimental to agriculture because of both long-run changes in average rainfall and temperature levels and greater instability.[27] However, the evidence supporting a pessimistic view of climatic change on agriculture is not convincing. For example, there was no agreement among climatologists attending a 1975 international conference on "climate

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[27] In an article in the February 1974 Fortune, Tom Alexander summarizes the views supporting a pessimistic conclusion regarding the impact of climatic change on agriculture. The impact of climate and weather fluctuations on U.S. agriculture and the measures required to counter potentially detrimental impacts of these fluctuations are examined in the recent National Research Council study Climate and Food.

change, food production, and interstate conflict" as to whether the global effects of climatic change, if such change occurs, would be beneficial or detrimental on balance.[28] Short-term variations in the climate and weather pose a greater threat to crop production than do gradual climatic changes. Short-term climate and weather fluctuations are the major cause of food production variations and a major component of farmers' risk. And since farming practices and investments are adapted to recent experience, climate and weather instability can be expected to have a negative impact on agriculture. Nevertheless, even if one accepts the view of increasing climate and weather instability, this alone is not sufficient cause for pessimism regarding the adequacy of agricultural resources and technology to meet food demand over the rest of this century. Rainfall variations are the prime source of production fluctuations, and investments in irrigation and drainage, research on new varieties with greater resistance to drought or flooding, and wider adoption of water-conserving farming practices offer ways to compensate for rainfall uncertainties. Furthermore, major advances in the ability to favorably influence some local growing environments through weather modification as well as improvements in the ability to forecast weather offer great potential in the coming decades for offsetting the negative impacts of climate and weather change and instability on agriculture.

As we move into the twenty-first century, the adequacy of land and water resources for agricultural expansion in the developing nations becomes less certain. Indeed, in the absence of major reductions in population growth, the food situation looks increasingly bleak as we move past the

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[28] See the conclusions and recommendations of the conference on "Climate Changes, Food Production, and Interstate Conflict" sponsored by the Rockefeller Foundation and held in Bellagio, Italy, from June 4-8, 1975.

year 2000. With a 2.7 percent annual rate of population growth in the developing market nations, the increase in food demand from population growth alone between 2000 and 2011 would be equivalent to 1970 aggregate consumption in these countries. Under similar assumptions, by 2030 food demand in the developing market countries would be nearly 6.5 times the 1970 level, and it would take only five years for population growth alone to increase demand by an amount equivalent to 1970 consumption.

While we have a fairly good idea of the technologies likely to influence agricultural production over the next decade, projections of available techniques are reduced largely to speculation and wishful thinking as we move into the twenty-first century. However, in the absence of a sharp reduction in population growth, it is difficult to imagine how most developing countries will be able to feed their people adequately for very long into the next century. Population increases would swamp any production increases foreseeable with existing technologies. While new advances can reasonably be anticipated, their impact would be quickly consumed by continued high population growth rates.

There can be little doubt that population growth in developing areas will decline sharply within the next thirty to fifty years. An underlying socioeconomic basis conducive to smaller families must be established if this reduction is to come primarily from voluntary decisions. Rapid rates of agricultural development can be an important factor in establishing these socioeconomic conditions.

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Chapter 4

NATURE AND MANAGEMENT OF ENVIRONMENTAL IMPACTS OF AGRICULTURE

Introduction

We have made no estimates of the economic costs of achieving the faster rate of growth in food production in the developing countries discussed in the previous chapter. Such an effort is far beyond the limits of this study, and probably would not be a fruitful exercise in any case, given the numerous uncertsinties involved. There is little question, however, that these costs will be high, requiring a mobilization of resources both in the developing countries and in the international community on a hitherto unprecedented scale.

The effort to achieve the higher levels of production almost surely will exact rising environmental costs as well. There is evidence, reviewed in chapter 5, that even at existing levels of production, agriculture in the developing countries is generating considerable environmental stress in some places. At the projected annual growth rate of about 3.5 percent production will double in twenty years, suggesting that environmental stress could spread and sharply intensify.

The view is often expressed, especially by spokesmen for the developing countries, that concern with environmental costs is a rich country luxury which the poor countries cannot afford. Expressions of this view were prominent in the deliberations of the 1972 Stockholm conference on the environment, although even among the developing countries there was no unanimity on the issue. The argument frequently is cast in terms of a "conflict" between preservation of environmental values on the one hand and economic development on the other.

We believe this view is based on a misunderstanding of the issues involved. Simply put, environmental impacts of development activities should be taken into account to the extent that they exact real social costs, no more no less. The nub of the issue, discussed below in the section on management of environmental impacts, is evaluation of those costs. The fact that environmental costs typically are not priced makes evaluation difficult, but it does not mean the costs are zero. If a country pays attention to the economic costs of agricultural development--and all of them do--then it should also pay attention to the environmental costs. Taking account of environmental costs is no more in "conflict" with development than is taking account of the cost of fertilizer.

The downgrading of environmental costs by developing countries is expressed in various ways, for example, that since investment funds are limited and environmental impacts frequently deferred, "development" should take priority over "environment"; or that measures to deal with environmental impacts, being a rich country concern, should be financed by the rich countries, and the costs not counted against the supply of development assistance funds from the rich countries. We believe this attitude toward environmental costs in the developing countries reflects the implicit belief that these costs are small, not that as a matter of principle they should be ignored. But this is an empirical issue. If for any particular development project it can be shown that the environmental costs are high, then even the strongest advocate of development must pay attention to them if his concern is to advance the national welfare. If he does not, the development objectives of the project will not be achieved.

This chapter discusses the nature of environmental impacts of agriculture and why they present special management problems. The next chapter gives a rough assessment of the seriousness of these impacts in the developing countries, both at present and over the next several decades as these countries attempt to accelerate the growth of food production.

Nature of Environmental Impacts

For purposes of this discussion the environment is defined as that part of the biosphere which surrounds and sustains, however indirectly, human life. It includes land, water, and air (including to the outer limits of the atmosphere) and all the forms of nonhuman life dwelling therein. Environmental impacts are changes in some part of the environment caused by human activity. The changes may be beneficial or damaging in their effects on the environment, although it is the damaging effects which, not surprisingly, are usually the focus of attention. Of course nonhuman events, such as climatic change not caused by human activity, can have profound effects on the environment as here defined. However, such effects are not considered in this discussion.

In the developing countries the environmental impacts of food production are those resulting from wind and water erosion, loss of animal habitat (caused, for example, by drainage of wetlands, clearing of forests, building of reservoirs), desertification, loss of soil fertility from leaching of nutrients and laterization, especially in tropical areas, unintended effects of fertilizers and pesticides, and a number of problems associated with the spread of irrigation (in addition to loss of habitat, mentioned above).

Wetlands provide a nesting place for migratory birds. When these lands are drained to convert them to crop production the dependent bird

population likely will be reduced unless alternative sites are available in the flyway.

Given the rate of deforestation in the developing countries--some indications of this are discussed in the next chapter--the resulting loss of animal habitat may be high. So far as we know there is no information on the extent of these losses, and in any case, there are other strong reasons to be concerned about deforestation, particularly its effects in promoting erosion, discussed below. Losses of habitat because of construction of reservoirs also is discussed below in connection with environmental impacts of irrigation.

Desertification--the spread of deserts--occurs, for obvious reasons, in arid and semi-arid zones. While it may occur because of climatic changes, it also reflects increasing pressure on land, water, and vegetation exerted by rising numbers of people and animals. These populations reduce the vegetative cover, thus exposing the land to increased risk of wind and water erosion. (While annual rainfall in such areas may be slight, it frequently is highly concentrated.) The resulting damage to the soil may be sufficiently severe to reduce the productivity of the land for many years, or even indefinitely.

Laterization is a problem peculiar to certain tropical areas where removal of forest cover exposes soils to heavy rainfall followed by drying under the tropical sun. These soils sometimes become so compacted and hard as to be useless for agricultural purposes. The combination of hot sun and heavy rainfall also is damaging to other tropical soils not subject to laterization. The increase in soil temperature destroys micro-organisms necessary to maintain fertility and the heavy rains break down the typically fragile soil structure, causing

rapid leaching of nutrients. The resulting loss of fertility so increases the cost of keeping these lands in crops that it may become uneconomical to do so.

The environmental impacts of fertilizers and pesticides, particularly the latter, have been widely discussed in the literature. The fertilizers of special interest are nitrogen and phosphorus. A principal concern is that some of these materials applied to fields will find their way into water bodies, including groundwater, where they may have damaging effects. Nitrogen in the form of nitrate may percolate into aquifers where it constitutes a health hazard, particularly to infants, if the aquifer is tapped for drinking water.

The more common problem of water pollution by fertilizer, however, is the effect of nitrogen and phosphate residuals that enter surface water bodies where they stimulate the growth of aquatic plants, thus increasing the burden on the water's supply of dissolved oxygen. Phosphorus is particularly important in this process because it more often is the nutrient limiting aquatic plant growth. Carried far enough, this process (eutrophication) will make the water unusable for recreation and spoil its capacity to support fish life.

There also is concern that some of the nitrogen fertilizers applied, after undergoing certain chemical changes, may rise to the upper atmosphere where it attacks the ozone layer. Since the ozone shields the earth's surface against ultraviolet radiation from the sun, reducing it would increase exposure to such radiation, thus increasing the risk of skin cancer.

Concern with pesticides in the environment has centered on unintended damage to plant and animal life, to human health, and even potential harm to the genetic stock of the race. The concern is well founded. There are well-known cases of unintended pesticide poisoning of wildlife and of humans,

of similarly unintended elimination of natural insect predators, and of accumulation through the food chain of persistent pesticides, particularly in fish and birds, with resulting damage to reproductive processes. Particularly troubling is evidence that some of the organochlorine compounds--aldrin and dieldrin, for example--may be carcinogenic in humans. While this is not proved--the evidence comes primarily from experiments on mice--the implications are serious, not only because of the high mortality rate of cancer but also because of the long latency period of the disease. If some of the organochlorine compounds cause cancer, the effects may not show up for twenty or thirty years. If society waits for such evidence before taking action to control use of pesticides, almost a whole generation will have been exposed in some measure to their potentially damaging effects. If society acts to control these materials without such evidence the supply of food may be unnecessarily less or more costly than it otherwise would be. Having banned the pesticides we will never know whether these additional costs were justified. This dilemma typifies one of the important problems in management of environmental impacts, discussed below.

The principal environmental impacts of irrigation result from the spread of water-borne diseases, particularly schistosomiasis (in developing countries), from damages to ecological systems, both in areas flooded by reservoirs and downstream from dams, and from increased soil salinity.

Schistosomiasis is caused by a worm which spends part of its life in water. In that stage it can penetrate the skin of humans with whom it comes in contact, after which it settles in the intestinal tracts or bladder, depending upon the species of the worm (of which there are three). Eggs produced by the worm are excreted and many of them re-enter the water

where they penetrate snails. After a period a new generation of worms emerges and the cycle is repeated.

The symptoms of schistosomiasis vary widely, depending upon severity of infection and other factors. While not ordinarily fatal, it may be extremely debilitating, causing recurring fever and diarrhea. The disease has been known for thousands of years. Its spread through time is not well understood, although many authorities think its prevalence increased rapidly afcer World War II. Two reasons were given: (1) movement of people from infected to uninfected areas; (2) the spread of large irrigation projects, exposing more people to infested water.[1] The reservoirs and canals created by these projects provide a favorable environment both for the schistosome and for its snail host. Moreover, the projects attracted increasing numbers of people, most of them with primitive notions of the relation between hygiene and health. In particular, use of irrigation canals and reservoirs as dumps for human excreta was widespread. Under these circumstances it is not surprising that schistosomiasis emerged as a major public health problem in the developing countries.

Apart from public health effects, the building of large dams may have extensive and complex impacts upon the environment in the area flooded by the reservoir as well as downstream.[2] The back-up of water impounded by the dam will destroy forms of riverine life not able to adapt to lake conditions. Unique plant and animal communities may be damaged or destroyed, and human settlements may have to be moved with all the economic and psychic costs that entails. In the area flooded by the Volta River project, for

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[1] Weisbrod and others, Disease and Economic Development, p. 47.

[2] The discussion in this and the following paragraph is based on Freeman, The Environmental Impact of a Large Tropical Reservoir.

example, 80,000 people had been resettled by 1971 at a cost of $34 million, over one-sixth of the construction cost of the dam and initial hydropower capacity.

The principal effects downstream from the dam result from reduction in the sediment load of the river (more sediment now being deposited behind the dam), and from changes in the quantity and timing of river flows. The reduced sediment load will diminish delta formation at the mouth of the river, possibly permitting increased wave erosion from the sea that may damage ports and other works of man. Nutrients carried by sediment typically will also be less, with potentially damaging effects on coastal fisheries. Changes in the quantity and timing of river flows, resulting from raising or lowering the reservoir in response to needs for irrigation, alter the seasonal fluctuation of salinity in coastal lagoons and estuaries, thus adversely affecting the growth of shrimp or other marine life whose life cycle was adapted to pre-dam conditions. Since many coastal waters and estuaries are highly productive, damages resulting from disruption of the seasonal pattern of fresh water in-flows to these water bodies may be high.

Irrigation may also increase soil salinity. Too much salt in the soil will inhibit plant growth, depending upon the plant, and in extreme cases will render the land useless for agriculture. All water used for irrigation carries certain amounts of salts. When the water is applied to the land, some of the salt is left in the soil after the water is drained off, percolates down, is used by the plant, or evaporates. Over time, the amount of salt will increase unless it is periodically flushed out by rain or by water applied specifically for that purpose. While the salt content of

the soil will increase if not flushed out, the salt content of irrigation return flows also will increase because these flows pick up some of the salt in the soil. Since the amount of the return flow is much less than the amount of water applied, the salt concentration of the water returned to the river is higher than that of water taken from the river. Repeated use of the river for irrigation as it flows downstream will steadily increase its salt content, creating problems for downstream farmers. The plight of the farmers in the Mexicali region of Mexico, dependent upon flows of the Colorado River out of the United States, is only one of the better known examples of a common problem.

Repeated irrigation may also raise the underground water table. If the table reaches the root zone of the plants, capillary action will carry water close to the soil surface, where it evaporates, leaving a salt residue. In time this process, if uncorrected, will greatly reduce or destroy the productivity of the land.

Environmental damages from erosion are of two sorts: (1) lower agricultural productivity because of the loss of topsoil, and (2) downstream damages, for example, accelerated loss of irrigation capacity and increased flood damages because of sedimentation of reservoirs, irrigation canals, and river beds. For soils of given natural fertility and natural rate of soil regeneration, the cumulative loss of productivity depends upon the original depth of the topsoil and the amount lost, the nature of the material underlying the topsoil, and land management practices. The nature of this relationship is complex and not well understood, but it seems likely that where topsoil is deep, amounts judged by competent authorities to be high can be lost without significant effects on productivity. In the United States, the Soil Conservation Service (SCS) estimates "acceptable" rates of topsoil

loss at 2.25 to 11.2 metric tons per hectare per year, depending upon depth and rate of natural soil regeneration. One centimeter of topsoil on a hectare of land weighs roughly 132 metric tons, almost twelve times the maximum "acceptable" annual rate of loss in the United States. There are many areas in the United States and other countries where the topsoil is sufficiently deep that annual losses of topsoil well in excess of the maximum "acceptable" amount could occur over many years before productivity would be much affected. Of course the annual loss of amounts of topsoil only slightly greater than that annually regenerated would, if extended indefinitely, eventually damage the productivity of even the deepest soils. The point, therefore, is not that where soils are deep the productivity consequences of erosion can be indefinitely ignored, but rather that the seriousness of the productivity loss for even "high" rates of erosion can vary widely from place to place.

The loss of productivity, where it occurs, is not necessarily, and perhaps not even generally, a net loss. The reason is that some of the eroded soil will be deposited at sites downstream where it is again available for agricultural use.[3] Some delta areas, for example, those of the Mississippi and the Nile, built by sediment resulting from erosion upstream, are among the most productive agricultural areas in the world. Some of this sediment, of course, comes from land in relatively low productivity uses, or which is wholly unoccupied, in which cases erosion, perverse though it may seem, actually adds to the productivity of the land by moving soil from where it has little use to places where it can be intensively used.

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[3]The discussion throughout refers to erosion by water. While wind erosion also is a problem--it was the erosion problem in the American Dust Bowl of the 1930s--it is not generally as important as erosion by water. Aside from the possible loss of soil productivity, some of the damages done by wind erosion, e.g., air pollution, are different from those of water erosion.

The extent of downstream damages from erosion depends upon the gross amount of erosion upstream, that is, the tons of soil moved off the land, the amount of this soil actually delivered downstream, and the nature and intensity of economic development downstream. For the area east of the Rocky Mountains in the United States a so-called "universal soil loss equation" (USLE) has been developed to estimate gross erosion from land in that area. The elements in the USLE which determine gross erosion are intensity and frequency of rainfall, susceptibility of the soil to erosion (essentially a matter of soil materials and structure), the slope and length of the land, cropping patterns, and measures taken to control erosion. While the USLE has been estimated only for the central and eastern United States, it is reasonable to believe that the elements in it would be important determinants of gross erosion in the developing countries as well. For example, it is plausible to expect gross erosion to be relatively high in mountainous areas where rainfall is high and seasonally concentrated, where farmers, for reasons discussed in the next chapter, employ few if any erosion control measures, and where much of the land is in crops such as corn or other row crops. This sentence describes the present situation in much of the Himalaya foothills, the Andean region of Latin America, the mountain areas of eastern Africa and parts of Indonesia and the Philippines.

"The amount of sediment delivered downstream" refers to the amount of soil eroded from a watershed which is deposited outside the watershed. This amount is determined by the amount of gross erosion (which, other things being the same, depends upon the size of the watershed) and the sediment delivery ratio, that is, the percentage of soil eroded in the watershed which leaves the watershed. Understanding of the processes underlying

the sediment delivery ratio is imperfect, but Renfro[4] has singled out five factors as particularly important in determining the ratio for soil eroded from farmer's fields: (1) proximity of the field to the stream; (2) the velocity and volume of water discharges and their frequency and duration; (3) the texture of eroded materials, fine silt and clay being more readily transported than sand; (4) the nature of depositional areas within the watershed, for example, the flatter the land and the more numerous the reservoirs, lakes, and ponds, the greater the proportion of gross erosion that will be deposited within the watershed; and (5) the size and topography of the watershed. Renfro cites statistical studies indicating a negative relation between watershed size and the delivery ratio, although no rationale for this finding is given. High relief topography is positively related to the sediment delivery ratio, for obvious reasons.

The product of gross erosion in the watershed and the sediment delivery ratio measures the amount of soil carried out of the watershed by the river. The amount of damage this sediment does depends upon where it settles and the nature and intensity of economic development downstream. For example, damages to reservoirs, irrigation canals, and to crops and other property from flooding, or the costs necessary to control these damages, will be greater if the downstream area consists of intensively cropped irrigated farmland and large population centers than if there is little or no development downstream.

Management of Environmental Impacts

The environmental impacts of agricultural production impose real social

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[4] Renfro, "Use of Erosion Equations and Sediment-Delivery Ratios for Predicting Sediment Yield," p. 37.

costs. The loss of reservoir capacity because of erosion, the illnesses and deaths resulting from nitrate or pesticide poisoning or schistosomiasis, the elimination of valuable wildlife, all of these are costly indeed to the groups or individuals who bear them. They represent a draft on available human and natural resources just as do the economic costs of pesticides, fertilizers, labor, land, fuel, and other inputs used by farmers. There is an important difference, however, between environmental costs and economic costs. Economic costs are borne by the farmers, or by whatever group generates them. Environmental costs are not. For example, the farmer pays for the resources required to engage in irrigated farming. Downstream farmers pay, however, for the damages imposed by the increase in water salinity resulting from irrigation return flows from the fields of the upstream farmer. Environmental costs, therefore, are a kind of "externality," that is, costs imposed by the activity of one actor on another for which no compensation is paid.

Since the farmer does not bear the environmental costs of his operations, in making his production and other management decisions, he will act as though the price to him of the environmental services he uses is zero, as indeed it is. This poses two sorts of environmental management issues concerning (1) the social efficiency of resource use, and (2) the distribution of income between the farmer who generates environmental costs and those who must bear them. We will refer to these as the efficiency issue and the equity issue respectively.

Achievement of a socially efficient use of resources requires that somehow environmental costs be "internalized," otherwise they will not be taken into account in resource allocation decisions. There is a considerable

literature on the internalization of externalities, and we do not propose to explore the issue here.[5] Suffice it to say that the dominant theme in this literature is that in societies which permit free bargaining among individuals and groups, such bargaining will result in the internalization of environmental costs and achievement of efficient resource use, so long as the costs of reaching agreement are less than the advantages agreement conveys. The essential condition for agreement is that the environmental costs exceed the costs of removing them. Given this condition, it is in the interest of the actor bearing the costs to offer the actor generating them a payment to stop or reduce whatever it is that imposes the costs.

The possibility of achieving a socially efficient management of environmental costs through private bargaining between parties involved was first pointed out by Coase.[6] Subsequent discussion of Coase's argument emphasized that the argument likely would not apply in situations where the numbers of people or firms suffering environmental damages are large and it is not possible for any single individual or firm to negotiate a reduction in damages to him (or it) without simultaneously reducing them to others as well. In such a situation the damages suffered by any single individual or firm likely would be too small to provide the basis for a deal with the polluter. Even if the damages were sufficiently large, the individual or firm would have an incentive to hang back, hoping that others suffering damages would negotiate a deal from which he (or it) would benefit, but

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[5]For a useful collection of papers dealing with externalities see Staaf and Tannian, Externalities: Theoretical Dimensions of Political Economy. For a more recent discussion and references see Krutilla and Fisher, The Economics of Natural Environments.

[6]Coase, "The Problem of Social Cost."

without costs. Under these circumstances, it may be very difficult for the damaged parties to organize themselves to negotiate effectively with the polluter even if the costs of organization are less than the gains organization would bring in reduced pollution damages. In these circumstances no deal would be struck, environmental costs would not be "internalized" and the environmental damages would continue. Total product would be less than the socially efficient amount.

The situation in which private negotiations prove difficult or impossible is typical of many of the environmental impacts of agriculture, particularly those transmitted by water and air. The damages inflicted downstream by saline water, suspended sediment and fertilizer and pesticide residues are likely to be felt over a large area and by numerous farmers and fishermen, people using the water for recreation, by those dependent on hydroelectric power (who find generating equipment damaged and reservoir life shortened by sediment) and so on. Similarly, those damaged by air pollution resulting from wind erosion from farmers' fields are likely to be numerous and dispersed.

In summary, "internalization" of environmental costs may prove difficult or impossible in situations in which bargains cannot be struck, for whatever reason, between the damaged and damaging parties. In such situations, achievement of a socially efficient allocation of resources and level of output would require the action of a public institution, or set of public institutions, to assure that environmental costs are taken into account in decisions about how to allocate agricultural resources and how much to produce.

There may also be a role for such institutions in situations in which bargains would produce socially efficient solutions but would result in a redistribution of income. Such situations raise questions of equity. To

illustrate the argument, suppose that the bargaining process is between upstream and a downstream farmer in a situation where the irrigation practices of the upstream farmer impose salinity damages on the downstream farmer. Suppose additionally, that, for whatever reason, these damages have recently risen sharply. As a result of the bargain the upstream farmer changes his irrigation practices to reduce salinity in his return flows and is fully compensated by the downstream farmer for the cost of doing this. He, therefore, is no worse off than before. The downstream farmer is better off than before the bargain was struck, but he may be worse off than before the recent rise in salinity damages. In that event his income will be less than before the rise in damages and he will have been forced to pay the upstream farmer to avoid an even larger reduction in his income. If the river is common property, the likely case, the downstream farmer may well view the imposition of damages on him by the upstream farmer as arbitrary and unfair, and the suggestion that he can reduce these damages by bribing the upstream farmer to stop doing something that in the eyes of the downstream farmer he has no right in law or equity to do in the first place may seem outrageous. That the resulting allocation of resources would be socially efficient likely will appear irrelevant to the downstream farmer.

It is the perceived arbitrariness of the action imposing damages upon him which excites the resentment of the downstream farmer and which creates an equity issue. Arbitrariness can be eliminated by creating rules for management of the river to maintain its quality, rules which of course would have to be considered fair by both the upstream and the downstream farmer (and all other users of the river). The equity issue posed by environmental impacts, therefore, no less than the efficiency issue, requires a public institution,

or set of such institutions, to establish and enforce rules for management of these impacts.

This is not the place for detailed discussion of appropriate forms and modes of operation of environmental management institutions. "Appropriateness" in these respects would depend upon specific circumstances of time and place, with existing legal and institutional modes for managing resources and dealing with social conflict of key importance. In the United States a Federal institution, the Environmental Protection Agency (EPA) has primary responsibility for controlling environmental impacts, including those resulting from agricultural production. The EPA depends upon administrative rulings to discharge its responsibilities. These rulings are subject to judicial review should one or more of the affected parties wish to dispute the rulings. Ultimately, the regulatory authority of the EPA rests upon the police power of the state, subject to interpretation by the courts.

The EPA and its mode of operation grow out of the American legal and political experience. Countries with markedly different experience likely would want and need a different sort of environmental management institution. Any such institution, or set of institutions, however, would have to perform three basic functions: (1) they must determine the nature and extent of the environmental damages, specifically the source of the damage, who is being damaged, and in precisely what way; (2) they must include machinery for reconciling the conflicting interests at play so as to promote both social efficiency and equity, essentially a matter of determining the weights to be assigned the various damages; (3) they must include machinery to ensure that the offending practice is eliminated or altered or that those damaged by it are compensated in a way consistent with the balancing of interests achieved under function (2).

Performance of the first function requires primarily scientific and technical expertise. Determining the source of nitrates or pesticides in ground or surface waters or of sediment in streams or reservoirs is a scientific and technical task. So is the job of estimating the resulting damages. Where the sources of pollution are numerous and dispersed, it may be difficult to identify and quantify the contribution of each. Damages may be hard to measure as, for example, in the case of some pesticides whose effects on plant and animal life are not well understood or may be long delayed.

The second function is essentially political in that it deals with conflicting interests in the society, seeking an outcome in which some lose and some gain, but which strikes a balance between efficiency and equity. In effect, judgments must be made about the relative social value of the interests in conflict. By what criteria are such judgments to be made? Suppose that performance of the first function demonstrates that use of a certain pesticide may under some, not clearly defined, circumstances cause cancer in humans. Should the pesticide be banned? If it is, agricultural production will be less by an amount which can be estimated with reasonable accuracy, and some people will live who might otherwise have died. The loss of agricultural production is a real social cost. Is it greater or less than the value of lives saved? It will not do to answer that the value of human life cannot be measured. All societies implicitly establish tradeoffs between the value of certain practices and human life. In the United States we do not ban automobiles even though they kill 40 to 50 thousand people every year.

To continue the example, suppose that elimination of the pesticide would so reduce food production that some people may die of starvation.

This would be unlikely in the United States, but it could occur in the developing countries where many people already live on the thin edge of subsistence. Now the managing institution must balance the value of the lives of some individuals or groups against that of others. By what criteria are such decisions to be made?

The point of the discussion is that institutions charged with reconciling conflicting interests in environmental issues must inevitably make judgments about the relative social value of these interests. Having good technical information about who is damaging whom, and how much, will be helpful, but in itself it provides no answers to the questions of value. No formula will provide the "correct" answers, nor is any particular institutional form or process guaranteed to do so. Perhaps the only general statement that can be made is that the managing institution should be so structured as to give a full hearing to all the interests significantly involved in any given conflict over environmental impacts.[7] Since some environmental hazards, for example, those resulting from the build-up of persistent pesticides, affect the interests of both future and present generations, the difficulties of adequately representing all interests at risk in environmental management decisions are obvious.

The third function of the managing institution, enforcement of its decisions, is essentially administrative, backed by whatever command of the police power it can muster. The managing institution would require machinery for

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[7] After this was written the U.S. National Academy of Sciences issued a report, Decision Making for Regulating Chemicals in the Environment, which proposes as a principle of equity in decisions concerning management of environmental impacts that consideration be given to the interests of potentially affected individuals in proportion to the anticipated effects of the decision on those individuals. When the decision has to do with chemicals or other materials likely to affect diverse groups in the society, the report proposed that ". . .the decision-making process should be as open and accessible as possible" (p. 23). These principles are the same as those we advocate in the text.

monitoring conformance with its decisions and for invoking sanctions when judged necessary. The monitoring activity would be technical in large measure, and if the institution has the capacity to perform its first function, it should be able to do an adequate job of monitoring. Whether it will be able to invoke effective sanctions will depend upon the backing it gets from those who control the police power. If the society, speaking through its political authorities, is convinced that the environmental impacts of agricultural production must be managed in the public interest, then the managing agency will have the enforcement power it needs.

Summary

The argument of this chapter can be summarized in four statements: (1) the environmental impacts of agricultural production impose real social costs; (2) these costs are inadequately reflected, or not reflected at all, in decisions about the allocation of agricultural resources where no one owns, or is responsible for managing, the media--water, air, and in some cases land--which transmit the impacts. The failure to deal adequately with these costs raises questions of social efficiency and equity in the allocation of agricultural resources; (3) in these circumstances proper management of environmental impacts requires creation of public institutions to establish and enforce rules to assure that environmental costs are taken fully into account in decisions about allocation of agricultural resources and that the distribution of these costs is perceived to be fair; (4) such an institution would have to perform three basic functions: (a) determine sources of pollution, individuals, or groups damaged by the pollution, and the nature of the damages; (b) assign weights to the damages and to the costs of reducing them, essentially a political task for which market values

often will provide little if any guidance; (c) enforce its rulings.

Solutions to the environmental problems posed by agricultural production will not be found in this study. This chapter has attempted, however, to define the nature of these problems and to indicate why they present special management difficulties. The following chapter seeks to advance the discussion a step further by reviewing, albeit lightly, the principal environmental problems posed by attempts to increase food production in the developing countries, at present and over the balance of the century. Chapter 7 presents a comparable treatment for the United States.

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Chapter 5

ENVIRONMENTAL IMPACTS OF FOOD PRODUCTION IN THE DEVELOPING COUNTRIES

Introduction

It is not the purpose of this chapter to examine all the environmental implications of the projected growth in food production in the developing countries, a task well beyond our scope. Instead we attempt to give a necessarily impressionistic view of the nature and extent of present environmental problems resulting from the agricultural production in these countries and to speculate on how those problems may change and intensify in response to accelerated growth of production in the future. While reliable information about the present situation is scarce and the future as always obscure, we believe the evidence is clear that the projected increase in food production in the developing countries raises the threat of major environmental damage.

The Present Situation

As noted in the previous chapter, the principal environmental impacts of agricultural production in developing countries are loss of habitat, loss of soil fertility in tropical areas to laterization and leaching of nutrients, desertification, erosion damages, pollution by fertilizers and pesticides, and a variety of problems associated with the spread of irrigation.

Judging from the relatively few references to it in the literature, loss of habitat, at least that resulting from drainage of wetlands, is of small importance in the developing countries, although specific populations

of animals--we usually think of birds in this connection--and of people dependent on them may be severely affected.

Some of the literature on tropical soils leaves the impression that soils susceptible to laterization are widespread, or even the dominant soil types in the tropics. According to Sanchez and Buol this is not so.[1] They assert that there are no reliable estimates of the prevalence of soils that will harden into laterite for the entire tropics. After a review of regional estimates of the areal occurrence of these soils, however, they conclude that soils susceptible to laterization make up about 7 percent of the total land of the tropics. While this is not a negligible amount, it suggests that the threat of laterization is not general throughout the tropics.

We have been unsuccessful in finding quantitative estimates of the amount of land in tropical areas now being degraded by removal of forest cover and converted to crops, with resulting leaching of soil nutrients and breakdown of soil structure. It is impossible, therefore, to form even a rough judgment of the present importance of this problem relative to other environmental costs of food production in the developing countries.

Desertification is important in some areas, the Sahelian region of Africa being most prominent among them in recent years. It is a problem also in some parts of the Indian subcontinent and Latin America. It poses a continuing threat in arid zones where increasing numbers of people and livestock combine with primitive technology and lack of conservation measures to over-tax the capacity of soil and water resources to sustain the existing

[1] Sanchez and Buol, "Soils of the Tropics and the World Food Crisis."

ecological system. Eckholm, who has undertaken a wide-ranging survey of this and other environmental problems in the developing countries, and whose work we have used extensively in this chapter, cites a study by Kassas for the United Nations Environment Program in which it is estimated that 6.7 percent of the earth's surface now classified (by Kassas) as desert is attributable to man's activities. According to Eckholm this is an area larger than Brazil. On the basis of this and other, admittedly fragmentary, evidence Eckholm concludes that "...desertification is a major world problem and is growing in magnitude."[2]

Judgments of importance are always relative and may differ among observers even when all have access to all relevant data. Judgments about the importance of environmental impacts are particularly subject to variation because so few reliable data exist. In the case of desertification, a study by the U.S. Agency for International Development, cited by Eckholm, indicates that some sixty million people in the developing countries "...live directly on the interfaces of deserts and arable lands..."[3] Relative to the total population of those countries of 2.7 billion, this is a small number. Moreover, the productive capacity of the land being lost to desertification is relatively low, being useful only for extensive grazing or low productivity crops. The potential productivity of the land, however, may be considerably higher in places where irrigation is feasible.

Whatever the importance of both present and potential damages resulting from desertification in the developing countries, they seem low

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[2] Eckholm, Losing Ground, p. 61.

[3] Ibid., p. 59.

by comparison with those caused by erosion. To our knowledge the most extensive survey of the present extent and seriousness of man-made erosion in those countries is by Eckholm. While erosion can occur as a serious problem even with advanced technologies applied to level lands, in developing countries it is most severe where high and rising population pressure combined with primitive technologies leads to deforestation of mountain slopes. The cutting of trees and other vegetation and breaking the soil for cultivation makes it easily movable by rain. The result is increased siltation of streams, irrigation canals, and reservoirs. Eckholm cites a substantial body of evidence of the effects of this in countries throughout Asia, Africa, and Latin America. Some pieces of this evidence, by no means conveying its full weight, are given here.[4] The occurrences of floods in the Indus plain of Pakistan increased in the 25 years ending in the late 1960s because of the rise of riverbeds resulting from deposits of silt washed down from the increasingly denuded slopes of the Himalayas. Moreover, the rising silt loads of the region's rivers are rapidly reducing the capacity of many of Pakistan's expensive new reservoirs. For example, the $600 million Mangla reservoir, which began operations in 1967, was built with the expectation that it would last for 100 years. Sediment measurements taken after a few years of operation showed, however, that life expectancy was only 50 to 75 years, and this estimate made no allowance for an increase in the rate of sedimentation caused by continued deforestation in the reservoir's watershed.

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[4] Ibid., chapters, 2, 5, and 7.

Increased flooding because of rising river bed levels is also occurring in India, Thailand, the Philippines, Indonesia, and Malaysia. Similar experience is reported from Nepal where studies show that in the agriculturally productive Terai region some river beds are rising 6 to 12 inches per year because of siltation attributable to deforestation in the country's mountainous zone. Erosion is also increasing in East Africa, where population pressure has led to deforestation of most of the highland areas, and in much of the Andean region of Latin America, for example, the Lake Titicaca Basin of Bolivia and Peru. In the Cauca valley of Colombia spreading deforestation has increased the intensity of floods and boosted the already heavy silt load of the region's rivers, contributing to accelerated sedimentation of reservoirs. Eckholm asserts that this latter effect may cost Colombia billions of dollars in lost hydroelectric benefits over the next several decades.

By no means does all of the erosion in mountain areas of the developing countries result from clearing land for crops or livestock. Much of it is attributable to the cutting of trees for firewood, not only for rural people but for urban dwellers as well. While it is impossible to separate the contribution of food production from that of cutting for firewood, the literature dealing with erosion in those countries leaves little doubt that both are important.

There is no comprehensive quantitative information indicating the importance of downstream damages of erosion relative to the loss of productivity of land in eroded areas. Eckholm asserts that among the various scientists and governmental officials on whom he relied in his study there is a wide consensus that in many mountain regions continuation of present trends for

two or three more decades would permanently reduce the capacity of those regions to support human life.[5] What this may mean in terms of annual losses of agricultural productivity in those regions is impossible to say. However, since the contributions to food production and national income of mountain regions generally is low relative to the contribution of plains below, the downstream damages are likely to be more important. The productivity of agriculture in the plains generally is much higher than in the mountains, reflecting not only more fertile soils but also higher investments in reservoirs, canals, and the transport infrastructure needed to serve agriculture. Moreover, concentrations of population and nonagricultural activity generally are higher in the plains. Consequently there are more people and more valuable property subject to damage in the plains than in the mountains.

Information about the present extent and seriousness of fertilizer pollution in the developing countries is fragmentary. Alexander says that studies in many parts of the world suggest that there is much nitrate in groundwater in some places and none in others, but that the reasons for the differences are unknown. In any case, methemoglobinemia in the tropics, as in the United States, is rare.[6] According to Alexander, eutrophication of surface waters is a problem in some parts of the LDCs, but such limited studies as have been undertaken point to municipal wastes as the principal source of nutrients. Brown and Eckholm also discuss the contribution of

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[5] Ibid., p. 97.

[6] Alexander, "Environmental Consequences of Rapidly Rising Food Output." (Alexander is on the faculty of the Department of Agronomy, Cornell University, Ithaca, New York.) Methemoglobinemia is a disease resulting from nitrate poisoning. Infants are particularly susceptible.

fertilizer runoff to eutrophication of surface waters in the LDCs but acknowledge that it is hard to measure. Their only specific reference is to the Philippines where "villagers are finding that the use of fertilizers in rice paddies is resulting in the eutrophication of local lakes and ponds..." and has lowered fish production.[7]

The extent of the threat of nitrogen fertilizer to the ozone shield is quite uncertain. In any event, the threat if there is one, is global, and the developed countries would bear most of the responsibility since they use much more nitrogen fertilizer than the less developed countries.

As in the case of fertilizers, lack of information makes it difficult to form a clear impression of the environmental damages of pesticide use in the LDCs. As noted in the previous chapter, there now is evidence that some of the chlorinated hydrocarbon compounds widely used in the developing countries, for example, dieldrin, aldrin, may be carcinogenic in man. If so, the effects may not show up for 20 or 30 years, and then be difficult to trace to these compounds because of the lapse of time and because man also encounters other carcinogenic materials in the environment. The seriousness of this threat, therefore, remains a subject of controversy, but its long-run potential for major damage appears high enough to justify strong efforts to find alternatives to these means of pest control.

Only scattered evidence is available about the unintended effects of pesticides on aquatic animals and birds in the developing countries. There are reports that Guatemalan cattle egrets are producing thin-shelled eggs and of reproductive failures and thin egg shells of double-crested

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[7]Brown and Eckholm, By Bread Alone, p. 50.

cormorants on islands off the northwestern coast of Mexico. For the cormorants a significant negative correlation has been established between shell thickness and body fat residues of DDT and PCB. These materials may also damage fisheries, especially estuaries, although there are no well documented cases of destruction of regional fisheries in the tropics.[8]

The unintended destruction of natural pest predators also is common in the developing countries. In some instances the short-term consequences for agricultural production have been disastrous, as happened in the Cañete Valley of Peru where heavy application of insecticides at first produced large increases in yields of cotton but the elimination of pest predators led to resurgence of the pest population with devastating results.[9] An interesting variant on this theme, recounted by McCaull, occurred in Sabah in the mid-1950s. As part of a malaria control program, DDT and dieldrin were applied inside houses to kill mosquitoes. The mosquitoes were effectively eliminated but the pesticides also kills roaches and lizards which were eaten by cats. Many of the cats died, leading to a population explosion of rats.[10]

A potentially more important unintended effect of insecticide use is the increased genetic resistance of insects. Experience in the United States in the use of insecticides on cotton vividly illustrates this phenomenon. From the early 1940s until the mid-1950s DDT and other organochlorine

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[8]Farnsworth and Golley, Fragile Ecosystems, p. 200.

[9]Barducci, "Ecological Consequences of Pesticides."

[10]McCaull, "Conference on the Ecological Aspects of International Development."

compounds were widely and effectively used to control insects attacking cotton. In the mid-1950s, however, it was discovered that the boll weevil, the bollworm, the tobacco budworm, and other major cotton pests had developed strong resistance to these compounds. In response many farmers switched to organophosphorus insecticides and to carbamates, but found a rapid increase in resistance of some insects, particularly the bollworm and tobacco budworm, to these materials also. Conway (from which the above information is taken) asserts that this situation was encountered also, although less dramatically with other crops such as apples and citrus in North America and cocoa in the tropics. He concludes that the problem "... is not a minor one nor is it restricted to special situations. It is a general and growing problem equal to, if not more important than, the direct consequences of pesticide use on wildlife and man."[11]

Problems of soil and water salinity arising from irrigation have reached troublesome proportions in many parts of the developing countries. Eckholm asserts that in Egypt, the Aswan Dam has eliminated the process by which annual flooding of the Nile flushed salts from the soil. As a result, water logging and salinity in the Nile valley have become major problems.[12] Irrigation in the Indus valley of Pakistan has a history stretching back to the beginning of recorded history, but water diversions on a large scale are relatively recent. By about 1960 water logging and salinity resulting from irrigation had reached the point that over 2 million hectares, a fifth of the cultivated area of the Indus plain, was severely affected,

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[11]Conway, "Better Methods of Pest Control."

[12]Eckholm, Losing Ground, p. 118.

and the damage was spreading at the rate of 40,000 hectares each year. In response, the Pakistan government launched a program to lower the water table, primarily by sinking thousands of tube wells. The water pumped was used for irrigation, thus flushing soil salts, and lowering the water table since much of the water applied was used by the plants or lost to evaporation. By the early 1970s it appeared that significant progress had been made in reducing the salinity and waterlogging problems, but it was recognized that the battle is a continuous one in which there is no final victory. Should control measures be relaxed, the problem would recur.[13]

Irrigated areas in other countries face the same problems. Over 6 million of India's 40 million irrigated hectares have been severely damaged by waterlogging and salinity, while in China salinity has reduced yields on at least a fifth of the irrigated land in some areas.[14] Almost one-third of the irrigated land along the Peruvian coast and at least half the irrigated land in the northeast of Brazil are affected by salinity and waterlogging. In the latter area yields on some of the affected lands are lower than before they were irrigated.[15]

There are no estimates of the value of damages from salinity in the developing countries. However, the percentages of land affected in varying degree in India, Pakistan, China and other important producing areas suggest that these damages are high.

Estimates of the number of people suffering from schistosomiasis vary. Weisbrod and others[16] cite a careful review of evidence for the period

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[13] Ibid., pp. 120-121.

[14] Ibid., p. 125.

[15] Ibid., p. 126.

[16] Weisbrod and others, Disease and Economic Development.

1955 to 1964 indicating 118 million infected people, over 74 million of them in Africa. Wright[17] gives a world figure of 124.9 million, 91.2 million of them in Africa, 25.2 million in Southeast Asia, and most of the rest in South America and the Carribbean.

There is a widely held presumption that because schistosomiasis frequently is so debilitating it must significantly reduce the productivity of people affected by it. Despite the plausibility of this presumption it is difficult to find hard evidence strongly supporting it. Weisbrod and coauthors[18] found that on the Caribbean island of St. Lucia schistosomiasis was significantly related to lower daily earnings by adult males, but not females. Weekly earnings were not related to the disease, however, as infected individuals worked more days per week than those free of the disease. Hence there was no significant difference between the weekly earnings of infected and uninfected male workers.

Weisbrod and his colleagues do not argue that their work is conclusive evidence that schistosomiasis does not affect labor productivity. They carefully review possible reasons why they failed to find a significant relationship, such as data errors, errors in specification of their model, and others, and adopt the view that severe effects of the schistosome either did not occur because of physiological compensation in the infected individuals, or if they did occur they took forms other than those studied. They state this view as a hypothesis needing further study rather than as a settled conclusion. Moreover, they assert that the questions of schistosomiasis' impact in other parts of the world, or in St. Lucia in the future, remain open.

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[17]Wright, "A Consideration of the Economic Impact of Schistosomiasis."

[18]Weisbrod and others, Disease and Economic Development.

Fenwick and Figenschou[19] studied the effects of a particular, but common, kind of schistosomiasis (Schistosoma mansoni) on the productivit of cane cutters on a sugar estate in Tanzania. On the estate bonuses were paid for cane cut above a certain amount. Workers were divided into three groups: uninfected, infected but not treated during the period of the study, and infected but treated. Mean bonus earnings for each group were calculated for six month periods in 1968 and 1969. It was found that in 3 of the 4 six month periods uninfected workers earned at least 11 percent more than infected workers. These differences were statistically significant. In the fourth six month period uninfected workers earned 6 percent more than the infected workers, but the difference was not statistically significant. Examination showed that this period was one of exceptionally heavy rainfall which greatly reduced opportunities to earn bonuses by anyone. Fenwick and Figenschou think this may explain the failure to find a statistically significant result for this period.

Because the bonus scales were complicated and the men worked in different fields, the differences in mean bonus paid reflected differences in days worked as well as differences in productivity. The data were analyzed to measure "pure" productivity effects and it was found that uninfected workers were about 3 percent more productive than the infected. The difference was significant. For technical reasons, Fenwick and Figenschou consider this estimate to be biased downward, and that the true difference was about 5 percent.

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[19]Fenwick and Figenschou, "The Effect of Schistosoma Mansoni."

While a 5 percent loss in labor productivity is not trivial, it indicates a much smaller economic impact of schistosomiasis than is attributed to the disease in much of the literature on the subject. Prescott,[20] after a careful review of this literature, including the contribution of Weisbrod and coauthors and Fenwick and Figenschou, concluded that the case for a clear and strong impact of the disease on productivity has not been made. We are inclined to give more weight than Prescott to the results of Fenwick and Figenschou particularly since in their study they deliberately excluded men too ill to work. Apparently, Weisbrod's sample also excluded such persons. Of course, not all the ill people in the study areas were suffering from schistosomiasis, but given the prevalence of the disease there is a reasonable inference that many of them were.

We conclude that schistosomiasis probably does reduce labor productivity, but that for many infected people the effect is small to negligible. Obviously much additional research needs doing, especially to focus on the relation between productivity and varying degrees of severity of the disease as measured by egg count in urine or stool.

This discussion has dealt with effects of the disease on measured productivity. Nothing has been said of its costs in suffering of people who may continue to work and perhaps to maintain productivity but who much of the time feel wretched. If these costs could be measured, the negative impact of the disease perhaps would emerge more clearly.

The building of large dams and reservoirs may cause damages to ecological systems over broad areas in the less developed countries, although there are no comprehensive quantitative estimates of these damages.

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20 Prescott, "Does Schistosomiasis Matter?".

There is much anecdotal literature, however, suggesting that the damages may be important in some instances and not so important in others. The downstream effects of the Aswan dam appear to have been large and damaging. The reduction or elimination of annual flooding greatly reduced the supply of nutrients previously supplied to land downstream as well as to coastal waters, and eliminated the annual flushing of salts from the soil. Reduced deposition of sediment in the Nile delta led to encroachment of the sea on ports and other coastal installations. Similar problems likely would emerge in the lower Mekong valley if plans now under consideration for construction of tributary and main stem dams are carried out.[21]

Downstream effects of the Volta dam, on the other hand, appear not to have been serious, in part because the river never was rich in nutrients.[22] Effects similar in some respects to those of the Aswan dam, but less severe, have been studied along the west coast of Mexico.[23] Management of the Cardenas reservoir for irrigation in the State of Sonora alters the seasonal pattern of fresh water inflows to a large coastal lagoon. The period of low flows, and resulting high salinity in the lagoon, coincides with a period in the life cycle of shrimp temporarily inhabiting the lagoon in which they are adversely affected by high salinity. The impact of the dam, therefore, has been to significantly reduce the value of the shrimp catch from the lagoon.

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[21]For discussion of downstream effects of the Aswan dam see chapters 10, 11, and 12 by George, Kassas and Worthington, respectively in Farvar and Milton, eds., The Careless Technology. For lower Mekong effects see chapter 14 by Bardach in the same book.

[22]Freeman, The Environmental Impact of a Large Tropical Reservoir.

[23]Cummings, Hueth and Lampe, "Managing Water Resources."

How important these impacts of large dams may be in the developing countries as a whole is impossible to say. Our guess is that the net damages are significantly less than those of salinity resulting from irrigation, but we emphasize that this is only a guess.

The Future Situation

In thinking about the magnitude of future environmental impacts of food production in the developing countries it is helpful to focus on the kinds of technologies farmers likely will employ to expand output. This is because for any given level and composition of output, the nature and extent of environmental impacts will depend upon the kind of technology employed. It is useful to think of these technologies as being either land-using or land-conserving. Land-using technologies expand production by bringing new land under crops while with land-conserving technologies the production increase is achieved by applying more non-land resources--fixed capital, labor, fertilizer, pesticides, irrigation water, and so on--to the existing cropped area. In the developing countries the principal environmental problems with land-using technologies are those associated with wind and water erosion, loss of animal habitat because of drainage of wetlands or land clearing, and, in tropical areas, loss of soil fertility from leaching of nutrients and laterization. The principal problems with land-conserving technologies are desertification (increasing pressure of people and animals on fragile arid zone ecosystems), pollution from fertilizers and pesticides, and various problems associated with the spread of irrigation.

Like any analytical device, the distinction between land-using and land-conserving technologies will not catch all the nuances of reality. For example, in many parts of the world--certainly in the United States--farmers who expand production by bringing in more land probably will apply fertilizers to that land and perhaps pesticides and other yield-increasing inputs as well. Consequently, the land-using mode of response may entail environmental costs of fertilizer and pesticide pollution as well as costs of erosion. To extend the point, farmers who adopt the land-conserving mode may nonetheless cause increased erosion by abandoning erosion control practices, such as strip cropping, in an effort to maximize production per unit of land. Since either mode of response may entail environmental costs associated primarily with the other, the two categories of technology should be regarded as polar cases, the actual technologies employed being chosen from the spectrum in between.

For reasons given in chapter 3, it seems likely that land-conserving technologies are likely to become increasingly important relative to land-using technologies in the agricultural development of the developing countries. To briefly recapitulate that argument, in the heavily populated countries of Asia, most of the arable land already is in crops and the quality of the remainder is such that costs of bringing it under crops would be high. Consequently farmers and public officials concerned with agriculture likely will find land-conserving technologies increasingly attractive economically relative to land-using technologies. In Latin America and Africa there still are large amounts of arable land not in crops, and in those areas land-using technologies are likely to look more attractive than in Asia. Even in Latin America and Africa, however, the appearance of large expanses of unutilized land may be deceiving. In

Latin America much of this land is in the Amazon basin. As noted earlier, many of the soils in that region quickly lose their fertility when the forest cover is removed. Keeping such land in regular short-term rotations likely would require large quantities of fertilizers and other special efforts to maintain fertility, thus increasing costs. Moreover, most of that region is far removed from markets and poorly served by the transport and other infrastructure needed to support a productive agriculture. The cost of installing the necessary infrastructure would be high. In Africa, land-using technologies likely would look particularly attractive if the tse-tse fly problem could be brought under control. This still has not happened, however, and until it does large parts of Africa will remain closed to agriculture. In these circumstances, land-conserving technologies may appear increasingly attractive relative to land-using technologies even in Latin America and Africa.[24]

We believe, therefore, that the environmental impacts associated with land-conserving technologies should become increasingly important relative to those generated by land-using technologies, with the increase most marked in Asia, less so in Africa, and least so in Latin America. This is not to say that environmental problems associated with land-using technologies will diminish in an absolute sense. On the contrary, we think they will increase. Indeed, in our judgment damages from erosion, particularly those downstream, are likely to exact the highest cost of any of the various environmental impacts of food production.

Within the set of land-conserving technologies, consumption of

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[24]This argument rests implicitly on the assumption that the price of fossil fuels, particularly petroleum and natural gas, will not rise so high as to more than offset the cost of bringing more land under crops. Land-conserving technologies are more energy intensive than land-using technologies, hence more sensitive to the price of energy.

fertilizers and pesticides is likely to increase more rapidly relative to irrigation than in the past. From the early 1960s to the early 1970s fertilizer consumption in the developing countries increased at an annual rate of almost 14 pe cent. Data for pesticides are less clear, but consumption of herbicides increased rapidly in many areas, with insecticides and fungicides setting a somewhat slower pace.[25] We do not expect consumption of these materials to grow over the balance of the century as fast as they did in the 1960s and early 1970s, but there is no good basis for projecting any specific lower rate. We arbitrarily select 10 percent annual growth for fertilizer and 9 percent for pesticides for the period from the early 1970s to 2000. These rates almost surely are too high, but we think is better to err on the high rather than on the low side in considering likely environmental impacts of fertilizers and pesticides.

Because the most promising lands for irrigation in the developing countries already have been developed and some presently irrigated land likely will be lost to salinity, we expect that over the balance of the century irrigation will expand at less than the 3 percent annual rate characteristic of the last several decades.[26] This does not imply, however, that environmental problems associated with irrigation will mount more slowly in the future than in the past. Soil and water salinity tend to build up over time. Thus irrigated lands not now suffering from salinity may in time be damaged unless preventive measures are taken. It may be, therefore, that the annual growth in the amount of land suffering salinity damage is more closely

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[25] Food and Agriculture Organization, Assessment.

[26] Brown and Eckholm, By Bread Alone; Subcommittee on Departmental Operations, Malthus and America. These two sources project 1 percent annual growth in irrigation in the developing countries.

related to the total amount of irrigated land than to annual additions to such lands. Since the amount of irrigated land now is much larger than it was a decade or so ago, the annual increase is the number of hectares suffering from salinity damage over the balance of the century may be substantially greater than in the past even though the annual percentage growth in irrigation is less.

The rate of spread of schistosomiasis is a function not only of the spread of irrigation but also of the numbers of people in contact with infested waters. Prospective rates of population growth in rural areas of the developing countries are such that, in the absence of increased preventive measures, the number of people exposed to the disease each year is likely to grow steadily for the next several decades.

While we believe that over the next couple of decades consumption of fertilizers and pesticides in the developing countries will grow even faster relative to the increase in both irrigated and non-irrigated cropland than in the past, we think it unlikely that the environmental impacts of fertilizer and pesticides will come to challenge in importance those resulting from irrigation and erosion. The reason is that present rates of consumption of fertilizers and pesticides in the developing countries are so low that even if each grows at the rates we have projected, consumption per hectare of cropland by the end of the century still would not be exceptionally high by comparison with present levels of use in the United States and other developed countries.

This argument implies, of course, that present levels of use of these materials in the United States and other developed countries do not impose unacceptably high environmental costs. A review of the evidence (see

chapter 7) satisfies us that this is the case at least so far as the United States is concerned. One must be cautious, however, in using this evidence to draw conclusions about the future environmental impacts of these materials in the developing countries. This is particularly true with respect to pesticides. Owing to generally lower educational levels, careless use of pesticides probably is more widespread in the developing countries than in the developed countries. The damages could be high since some of the organophosphorous pesticides coming into increasing use are highly toxic to humans. Moreover, much of the increase in agricultural production in the developing countries over the balance of the century will be in tropical and sub-tropical areas. The build-up of insect resistance to insecticides, mentioned above as an increasing threat, and the increase in numbers of pests when natural predators are unintentionally destroyed may be more rapid in these areas than in the temperate zone characteristic of most of the developed countries. This is because pests in the tropics and sub-tropics have more generations per year than in the temperate zone.[27]

Rates of accumulation of DDT and similar compounds in the body fat of animals may also be greater in the tropics than in the temperate zone. This could occur if, as may be the case, rates of food consumption and respiration are higher in the tropics.[28] Moreover, "If carnivorous species are more abundant in the tropics, if food chains are longer, and if second and higher order carnivores occur more frequently, then not only is the number of species likely to suffer severely from DDT contamination much greater in the tropics, but also the 'average' tropical carnivore will receive

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[27] The Institute of Ecology, Man in the Living Environment p. 128.

[28] Farnsworth and Colley, Fragile Ecosystems p. 201.

more residues and be more severely affected than the 'average' temperate zone carnivore."[29] Since carnivore predation appears to be a more important regulator of ecosystems in the tropics than in temperate zones, the greater exposure of tropical then temperate zone carnivores to pesticide damage suggests that given quantities of these materials may have more disruptive ecological consequences in the tropics than in the temperate zone.

These considerations suggest that the experience of the developed countries in the use of fertilizers and pesticides may be a faulty guide to likely future environmental effects of these materials in the developing countries. Nevertheless, our present judgment is that in thinking about the environmental impacts of increasing agricultural production, these countries, at least over the next decade or so, probably should give highest priority to problems of erosion and public health and salinity impacts of irrigation. Unlike pesticides and fertilizers, these already present major environmental threats. They will continue to do so even without additions to irrigated area or new land development. Since more land is sure to be brought into production and irrigation to spread, these already serious problems will become more acute unless corrective measures are taken to deal with them. The question of management of environmental impacts of agricultural production in the developing countries thus must be addressed.

Position of the Developing Countries in Managing Environmental Impacts

The developing countries may find it more difficult to deal with environmental issues than the developed countries, where they are difficult

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[29] Ibid.

enough. The supply of the necessary technical and scientific skills is much less in the developing than in the developed countries. Of course, foreign experts can be contracted, as they frequently have been, but this clearly is less desirable than using nationals, were they available. The experience of the foreign expert likely will be with temperate zone agriculture and technology while many of the most pressing environmental problems of the developing countries involve tropical agriculture. Of course, the foreign expert can learn, but that takes time. Moreover, he may have language difficulties, his stay likely will be fleeting relative to the size of the problem he studies, and he surely will be expensive. Hence the scientific and technical expertise available to the developing countries for dealing with environmental impacts is likely to be in short supply for a long time to come.

If we are right in thinking that the problems of erosion, salinity, and water-borne disease are likely to be more important in the developing countries than the problems of fertilizer and pesticide pollution, then the shortage of scientific and technical skills should be less severe than if the priorities among the problems were reversed. A reading of the literature on environmental impacts of agriculture suggests that the technical aspects of fertilizer and pesticide pollution and control are much less well understood than those of erosion, salinity, and water-borne disease.

Devising institutions to mediate and reconcile the conflicting interests involved in environmental issues may also be more difficult for the developing than for the developed countries. The discussion of this problem in the previous chapter emphasized that any environmental management

institution must seek to strike a balance between efficiency and equity in dealing with environmental issues. Furthermore, to fully serve the public interest, all conflicting interests must be adequately represented in the process by which decisions are made. Devising an institution, or institutional structure, to achieve this in the developing countries may prove very difficult. Such institutions need a social setting favorable to active, broad-based citizen participation in local, regional, and national organizations formed to promote and protect the particular interests of particular groups in the society. The setting throughout much of the less developed world has not favored such organization. The tradition of grass roots mobilization to promote grass roots interests is weak. In good measure this must reflect the quite unequal distribution of economic and political power in these countries, a situation particularly marked in rural areas where many of the conflicts over environmental impacts of agriculture are likely to be more acute. Whatever the reason, the result is that it may be very difficult to establish and maintain the principle that environmental management institutions should be structured to give full representation to all interests involved in environmental issues.

Management of erosion may prove particularly difficult. While the causes of erosion and techniques for controlling it are reasonably well understood, implementation of effective control measures will face many obstacles. As noted earlier in this chapter, the problem is particularly severe in places where population pressure combined with primitive agricultural techniques is pushing people to remove vegetative cover in mountainous areas. The best way of reducing erosive pressure on the land in these areas is by reducing the number of people and promoting the adoption of management techniques that conserve rather than destroy the soil. Neither of these measures will be easily achieved. The

momentum of population growth in rural areas is such that it cannot be appreciably slowed in the next decade or so by the spread of family planning programs. Unless mortality rates rise, and of course this is not a policy option although it could happen, the best hope for slowing population growth in rural mountainous areas is by stimulating out-migration. This presumes attractive economic opportunities elsewhere which induce people to move. While the growth of such opportunities can be expected if the general economic performance of the developing countries does not falter, the rate of growth may fall short of that needed to significantly lessen pressure on the land. Urban centers throughout the developing world already are hard pressed to absorb the increasing flow of migrants from rural areas, while in many developing countries the growth of economic opportunity in rural areas is impeded by land tenure systems and government policies which inhibit adoption of labor-intensive technologies. Indeed the highly unequal distribution of land characteristic of many of these systems is a main cause of the spread of people up the mountain slopes; the only place they can get access to land.

The adoption of effective erosion control techniques in these areas is discouraged by the difficulty of establishing clear title to individual plots, or by the fact that the land may be held in common. In such circumstances, the farmer has little incentive to adopt erosion control measures since they inevitably cost him something but he has no assurance that he alone would reap the benefits. This is a form of the "common property" problem, the key characteristic of which is a socially wasteful rate of exploitation of the resource held in common. One way to attack the problem is to devise an institutional structure which gives managers of the resource incentives to exploit it more slowly. This may be accomplished by establishing separate property rights to parts of the resource or by

arranging for central management of it. In either case future benefits from exploitation of the resource are likely to be more heavily weighted relative to immediate benefits than if all have open access to the resource.

This should reduce but it will not solve the erosion problem so long as farmers (or other managers of the land) do not bear the costs of downstream damages. Damages in the form of reduced productivity also may continue if the farmers' (or managers') time horizon is shorter than that of the society as a whole. This may well be the case for the hundreds of millions of small subsistence farmers who are necessarily so concerned about getting through today that they have little time to worry about tomorrow. Such people may have weak incentives to conserve the land, even if they own it.

The discussion indicates that the erosion problem in the developing countries is primarily social, economic, and political rather than technical. Its solution in the long term accordingly will require a complex mixture of policies relating to population control and distribution, growth of non-farm economic opportunities, and change in the institutional structure shaping land management decisions. So stated, it is clear that the erosion problem in the developing countries likely will endure for a long time, a serious continuing threat to the environmental integrity of those areas.

Management of irrigation induced salinity and public health problems such as schistosomiasis also probably are more political and social than technical. The planners and managers of large irrigation projects know very well that the projects will give rise to salinity problems unless adequate preventive measures are taken, for example, provision of adequate drainage and diversion or desalination of irrigation return flows. Often,

however, the problems do not become serious until some years after the projects are brought into operation, and the measures to control them may be expensive. Given the pressure on policy makers and planners to show quick results at lowest cost, there is a temptation to underinvest in, or ignore entirely, these control measures even though their importance is acknowledged. This clearly is a political issue of a type by no means confined to the developing countries, that is, the tendency of politicians to underweight the importance of problems not expected until after the next election.

While the epidemiology of schistosomiasis is not perfectly understood, it is clear that the prevalence of the disease could be vastly reduced if people could be induced to adopt modern procedures for disposing of human wastes. The provision of sanitary toilet and sewage disposal systems to entire populations in affected areas may be a simple technical problem, but it faces difficult social and economic obstacles. It obviously will be a long time before the level of development in most of the developing countries will be such as to permit a modern toilet in every rural household. Meanwhile, in many places public facilities at the village level could be economically feasible and adequate to break the schistosomiasis-snail-human host cycle if people could be persuaded to use them. For reasons that are not entirely clear, community toilets have not been widely accepted where they have been provided (referring here primarily to experience in Africa) although community water systems have. In any event, people are not likely to break old habits of personal hygiene unless they understand the connection between present modes of human waste disposal and infection and believe that avoidance of infection is worth the inconvenience of abandoning the traditional ways. Given the prevalence of the disease, the remoteness of many of the affected areas from centers of public health

expertise, the ignorance of affected populations of the sanitation-disease relation, and the hesitant commitment of public health authorities to mount a major attack on the disease, it is clear that reducing the prevalence of schistosomiasis in the developing countries may prove very difficult.

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Chapter 6

RESOURCE IMPLICATIONS FOR THE UNITED STATES OF INCREASING FOOD PRODUCTION

Introduction

Chapters 2, 3 and 5 dealt, respectively, with the gap between food demand and production in the developing countries, the resource implications of attempts in those countries to accelerate food production to close the gap, and the environmental problems that might arise from this effort.

This and the following chapter address the same set of issues in the United States. This chapter takes as a point of departure alternative projections of growth in food production in the United States and considers some of the resource implications of each. The following chapter considers the principal environmental impacts implicit in the projections of production and discusses some of the policy issues that may arise in dealing with these impacts.

The United States is the major supplier of grains to the developing countries, and if the gap between demand and production in those countries projected in chapter 2 should emerge, the United States could be expected to fill most of it. Consequently, the level of U.S. exports and production of food is dependent in some degree on the success of the developing countries in meeting their own demands for food. The greater their success, the lower our exports, other things the same. However, the United States is a major food exporter to other countries as well; consequently, developments in those other countries as they may affect demand for our exports are important, whatever may occur in the developing countries.

Projections of U.S. Food Production and Exports

The U.S. Department of Agriculture (USDA) has made a number of projections to 1985 of United States production and exports of agricultural commodities. Two sets of these projections, for wheat, corn, all feed grains and soybeans, are given in table 12 along with comparable figures for 1975/76. There are two reasons for focusing on grains and soybeans: (1) they presently account for about two-thirds of the harvested cropland in the United States; (2) they account for an even larger share of the harvested cropland devoted to export and, as we shall see, it is variations in exports which will determine whether the pressure on U.S. agricultural production capacity is light or heavy.

The projections in table 12 were produced by a mathematical model of the world grain-oilseeds-livestock economy prepared by the Foreign Demand and Competition Division of the USDA.[1] The basic inputs to the model are population and income growth, demand and supply price elasticities, input variables (e.g., fertilizer), and assumptions about underlying economic trends and policies affecting agriculture around the world. Data for 1969-71 were used to determine the value of the constants in the equations. However, in deriving the projections an attempt was made to take account of changes in preferences among various foods, particularly the increasing preference for meat as income rises, for changes in resource constraints, and for trends in crop yields. The model consists of a set of simultaneous equations which can be solved for equilibrium values of area, yield, production, food and feed use,

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[1] See USDA, "Alternative Futures" for a detailed description of the model. The projections were taken from computer printouts of various model runs dated July 13, 1976.

Table 12. Production and Net Exports of Grains and Soybeans in the United States

(millions metric tons)

	1975/76		Projections to 1985							
			Baseline		High demand		Percent change from 1975/76			
							Baseline		High demand	
	Production	Exports	Production	Exports	Production	Exports	Production	Exports	Production	Exports
Wheat	58.0	30.3	58.4	33.5	74.4	50.0	0.7%	10.6%	28.3%	65.0%
Feedgrains	186.0	48.4	227.2	39.4	269.4	62.0	22.1	-18.6	44.8	28.1
Corn	150.2	42.0	177.8	33.4	207.8	54.7	18.4	-20.5	38.3	30.2
Soybeans	37.8	14.9	57.8	25.9	63.2	27.7	54.9	73.8	67.2	85.9

Sources: Data for 1975/76 are averages for those years from USDA, Agricultural Outlook, December 1976; 1985 projections prepared by the USDA, Foreign Demand and Competition Division. Those for wheat and feedgrains are in "Alternative Futures for Food in World Grain-Oilseeds-Livestock Economies," August 1, 1975. Those for corn and soybeans were provided to the authors by the Foreign Demand and Competition Division. The baseline projections are those of Alternative I in "Alternative Futures"; high demand projections are those of Alternative II. The principal assumptions underlying the projections are discussed in the text. Feedgrains consist of corn, grain sorghum, oats, and barley.

trade and prices in all major regions of the world. Table 12 shows a few of those results for the United States.

The baseline projections in table 12 assume that population in the United States will be 236 million in 1985, up from 213 million in 1976. Real per capita income is assumed to grow by 3 percent annually from 1973 to 1985. Population and per capita income in the rest of the world are assumed to grow at the same rates as those underlying the projections in table 2, chapter 2. With respect to policies, the baseline projection assumes that the European Economic Community maintains high prices for internally produced grains, stimulating production and resulting in barriers against increased imports. The Soviet Union, Eastern Europe, and China continue policies of gradually liberalizing imports but also stimulate the growth of internal grain production.

The net result of these various economic and policy factors is that world trade in grains and soybeans (and other oilmeal products) continues to grow from 1975/76 to 1985 in the baseline situation. The United States maintains its current position in the soybean trade (roughly 70 to 75 percent), increases its share of trade in wheat, and loses ground in feedgrains.[2]

The high demand projections in table 12 assume that population in the United States will be 244 million in 1985 and per capita income will grow by 3.3 percent annually from 1973 to 1985. These higher projections of domestic

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[2]The U.S. share of world trade in wheat and feed grains in 1975/76 was 47.8 percent and 62.5 percent respectively (USDA, Foreign Agriculture Circular: Grains). The baseline projection shares are 52.0 percent for wheat and 58.0 percent for feed grains (USDA, Foreign Demand and Competition Division computer printouts, July 13, 1976).

population and income growth result in higher levels of domestic use of grains and soybeans in the high demand situation than in the baseline case. However, the major differences between the baseline and high demand projections reflect differences in the assumptions about income growth and trade policies in other countries.[3] Per capita income in both developed and developing countries is assumed to grow significantly faster than in the baseline projection. With respect to trade policies, it is assumed that the European Economic Community adopts less restrictive trade policies and lower internal price targets than in the baseline case, thus permitting a higher level of grains imports. It also is assumed that the Soviet Union and Eastern Europe are more open than in the baseline case to imports of grains and oilmeal in order to support faster growth of their livestock economies; that China more rapidly eases restrictions against grain imports; and that the livestock economies, particularly poultry, of the developing world grow faster than in the baseline case, especially in countries enjoying high rates of income growth because of high petroleum revenues.

An implication of these various assumptions underlying the high demand situation is that the U.S. share of world trade in wheat rises to 57.5 percent in 1985 (from 47.8 percent in 1975/76) and its share of the trade in feed grains rises from 62.5 percent to 67.5 percent.[4] The U.S. share of the soybean trade remains at roughly 70 to 75 percent.

In our judgment, the two sets of assumed conditions with respect to the United States and world population and income growth and trade policies are

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[3]Population growth outside the United States is assumed to be the same in the high demand situation as in the baseline.

[4]Net imports of grains by the developing countries are 70.5 million tons in the high demand projection for 1985, virtually the same as that shown in table 6, chapter 2.

both plausible conjectures of the way the world might look in 1985. If either set of conditions prevails, then the corresponding levels of U.S. production and exports of grains and soybeans could reasonably be expected, assuming that the competitive position of the United States in world markets for these commodities remains about the same as in 1975/76. Consequently, we do not propose a detailed evaluation of the projection, confining our comments to just one aspect of the projections: the role of the Soviet Union in the world grain trade.

The baseline projection is that the Soviet Union will have net imports of 8.5 million metric tons of grains in 1985. The high-demand projection is for 11.9 million metric tons. It is not assumed in either case that the United States would be the only supplier of these imports, but it probably would be dominant.

Since the mid-1960s, net grain imports in the Soviet Union have fluctuated wildly, rising from 0.9 million metric tons in 1965-67 to 20.8 million tons in 1972/73, falling to 5.2 million in 1974/75, then rising to 25.6 million in 1975/76.[5] These fluctuations reflect efforts by the Soviet Government to maintain stable growth in the country's livestock industry in the face of large annual variations in grain production caused by inter-annual changes in the weather. According to a study by the U.S. Central Intelligence Agency reported in Science,[6] the weather in the Soviet Union was also responsible in large measure for a rising trend in Soviet grain production which began in the early 1960s. For evaluation of long-range projections of Soviet grain imports, trends in production are more important than annual

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[5]Data for 1964-67 from USDA World Grain Trade Statistics: 1950-61--1972-73. Data after 1965-67 from USDA Foreign Agriculture Circular.

[6]Science.

fluctuations. If the trend evident in the 1960s were to persist, the projection of United States grain exports in table 12 could turn out to be too high, perhaps by a substantial amount.

The CIA study questions whether the upward trend of the 1960s in Soviet grain production will persist. The author of the study argues that the weather in the principal grain producing regions of the Soviet Union was unfavorable in the early 1960s, depressing yields, and favorable in the late 1960s, elevating yields and giving a marked upward tilt to their rate of increase. According to the study, the weather in these regions turned unfavorable in the early 1970s, a trend expected to last at least into the early 1980s. In that event, the increase in yields would be slowed if not reversed, with a consequent slowing in the growth of grain production. Production could average only some 200 million metric tons per year, 15 to 20 million tons short of goals set in the official plans for the five years ending in 1980, thus creating a need for imports.[7]

Statements about future long-term changes in the weather and their consequences are always subject to high discount, even when they are made by competent scientists. Consequently, the CIA study is not cited here as conclusive evidence that the Soviet Union will remain a net grain importer at least into the 1980s. The study does suggest that this may be the case,

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[7]According to the Science article, Wayne Decker, a climatologist at the University of Missouri doing a study for the USDA of long-term trends in the weather, agrees with the finding of the CIA study with respect to changes in weather in the Soviet Union since the early 1960s.

It is worth noting that in 1976 weather in the grain-producing areas of the Soviet Union was favorable and a record crop in excess of 220 million metric tons was harvested. And based on weather conditions through June 1977, the 1977 crop was projected to be as large as or even larger than the previous crop.

however, and suggests even more strongly that the Soviets will not likely emerge as important grain exporters in that period. The study thus gives some support to the USDA's projections of relatively modest Soviet imports of grain in 1985, in both baseline and high demand situations, and by implication to the projections of United States grain exports shown in table 12.

Factors Affecting Resource Use

The Role of Technology

Meeting either of the projected levels of grain and soybean production will increase the demand by American farmers for resources. The amount of the increase for each type of resource depends upon the kinds of technologies farmers choose. We assume that in making these choices, farmers seek to maximize their incomes, and that the choices are conditioned by two sets of factors: (1) the prices and productivities of alternative technologies; (2) public policies. The policies of particular interest here are those designed to encourage farmers to withhold land from production and other policies to protect the environment.[8]

Technological Choices: The Historical Record to 1972

Prices. In the last chapter we distinguished between land-using and land-conserving technologies, the former being characterized by a large amount of land relative to other inputs to produce a unit of a given crop and the latter by little land relative to other inputs.[9]

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[8] Farmers' choices among technologies may also be influenced by other policies, e.g., minimum wage laws. Most of these other policies would be reflected in prices of various inputs and hence would be taken into account in our analysis of prices of alternative technologies.

[9] See chapter 5, pp. 113-114 for a discussion of the two categories of technology.

From the end of World War II until 1972, the relative prices of these alternative technologies favored the land-conserving mode. The average price of fertilizer, the principal land-conserving input, increased by 13.7 percent between 1946-50 and 1972, while the average value of a hectare of farm real estate rose by 113 percent.[10] Energy prices rose by 46 percent between 1946-50 and 1972,[11] much less than the increase in the value of farm land. Irrigation, a highly land-conserving technology, increased by 5.3 million hectares or 55 percent from 1949 to 1969, a period in which total cropland harvested declined from 143 million hectares to 116 million hectares.[12] Fifty-eight percent of the increase in irrigated hectares was in Texas, Oklahoma, Kansas and Nebraska where irrigation is mostly by pumping groundwater.[13] Energy is an important element in the cost of pumping.

Energy also is significant in the cost of operating farm machinery, another important component of land-conserving technology. The prices of farm machinery rose somewhat faster than the price of land between 1946-50

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[10] USDA, Agricultural Statistics 1967 and 1973 for fertilizer prices; Economic Report of the President 1977 value of farm real estate. We assume that changes in the national average value of an hectare of farm real estate reflect changes in the price of land farmers consider when deciding whether to bring in more land or use present land more intensively. The rental value of land probably would be a better measure of this price because it likely would reflect more accurately the value of the land in agricultural production. The per hectare value of farm real estate also reflects the value of the land in agricultural production, but in addition it is influenced by the speculative value of the land in non-farm uses. The USDA publishes an index called "farm services and cash rent" but it begins only in 1971. We are comforted by the fact that between 1971 and 1975 this index moves very much like the index for per hectare value of farm real estate.

[11] Economic Report of the President 1977, p. 225.

[12] USDA, Our Land and Water Resources, p. vii.

[13] Data on irrigated land are from Agricultural Statistics 1973.

and 1972, as did the prices of motor vehicles and wages of hired labor. On average, however, the prices of all inputs bought for use in production (except labor) increased only slightly more than 50 percent in this period, less than half the increase in the value of land.[14]

Productivity. The price conditions favoring land-conserving technologies prior to 1972 were strongly reinforced by the high potential of these technologies to increase productivity. The basic components of these technologies were improved seed varieties, hybrid corn being the outstanding example; improved cultivation practices such as planting and pruning for maximum leaf area; fertilizers; farm machinery; and chemical pesticides. In many areas irrigation also was an important component of this technology. The high productivity potential of these technologies is evidenced by the rapid increases in crop yields and total productivity achieved between 1950-52 and 1971-73 (table 13). These increases were among the highest in the world in that period.[15]

Table 13. Average Annual Percentage Rates of Increase in Crop Yields and Total Agricultural Productivity in the United States

	1950-52 to 1971-73
Yields	2.3%
Total Productivity	1.9%

Source: USDA, Changes in Farm Production. Total productivity is the ratio of an index of all farm output to an index of all inputs.

[14] USDA, Agricultural Statistics, 1967 and 1973.

[15] Indexes of crop yields and total agricultural productivity are not available for other countries. However, between 1950-54 and 1971-73 only Mexico and France had higher rates of increases in wheat yields than the United States, only France and Italy had higher rates of increases in corn yields, and only Australia had higher rates of increases in rice yields. In 1950-54, Mainland China accounted for 59 percent of the world's soybean acreage and the United States for 31 percent. By 1971-73 the United States' share had increased to 60 percent, China's had declined to 21 percent, and Brazil had 8 percent. Soybean yields in the United States increased faster than in either China or Brazil in this period. All of these data are from USDA, Agricultural Statistics, 1961 and 1974.

Policy. Beginning in the 1950s and continuing to 1972, there were a variety of federal government programs designed for soil conservation and to reduce production to help maintain farm prices. Under these programs, farmers were provided inducements to withhold land from production. The amounts of land withheld fluctuated considerably over this period, but always numbered in tens of millions of hectares. These programs, therefore, strengthened farmers' incentives to adopt land-conserving technologies.

Although we have seen no systematic analysis of the issue, it seems likely that, compared to economic factors, policies to protect the environment had relatively little influence on farmers' choices of technology in the post-war period up to 1972. Policies to reduce erosion no doubt encouraged farmers to take some land out of production, for example, in New England and Appalachia, but much of this land was of relatively low productivity and likely would have been turned to other uses anyway, given the then prevailing downward pressure on farm commodity prices. The only effective regulations on farm chemicals in this period were those relating to pesticides under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) of 1947. The Act required the registration of pesticides prior to their sale or movement in interstate commerce and contained other provisions to assure safe use. Whatever constraints may have been imposed by the Act, pesticide use rose very rapidly between the early 1950s and 1972. No important pesticide in common use was banned in this period, the first important action of this sort, that of the Environmental Protection Agency against DDT, not coming until the middle of 1972.

Patterns of Resource Use. The pattern of resource use in the post-war period to 1972 clearly demonstrated the dominance of land-conserving

technologies. Cropland harvested declined from an average of 137 million hectares in 1950-52 to 117 million hectares in 1972, but irrigated land doubled to a level of nearly 16 million hectares. The quantity of all purchased inputs increased by 50 percent, and the quantity of these inputs per hundred million hectares of harvested cropland rose 70 percent.[16] The increase in use of agricultural chemicals (fertilizers, pesticides, and lime) was especially rapid, amounting to 262 percent.[17]

Technological Choices: The Historical Record After 1972

Prices. From 1972 to 1975 the increase in the average price of all non-land inputs was 81 percent of the increase in farm real estate value. From 1946-50 to 1972 the average price of non-land inputs increased only 45 percent as much as the increase in farm real estate value. Consequently, the change in price relations after 1972 was substantially more favorable to land-using technologies than the change in the two and one-half decades prior to that year. Fertilizer prices in particular rose sharply relative to land values, 131 percent compared to 63 percent. The price of fuel and energy purchased by farmers rose by 64 percent, much faster relative to land values than before 1972. We have seen no quantitative information showing the effect of the relatively fast rise in the price of energy on the economic attractiveness of irrigated relative to dry land farming but at the margin it must have favored the latter.[18]

Productivity. Changes in the productivity of farm technologies may also have encouraged farmers to give more weight to the land-using mode after 1972.

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[16] USDA, Changes in Farm Production.

[17] Ibid.

[18] All of the data in this paragraph are from USDA, Agricultural Statistics, 1976.

The increase in crop yields, which had been rapid in the 1950s and 1960s, slowed markedly from the early to the mid-1970s, as did the rate of increase in total productivity (table 14).

There are a number of possible explanations for the performance of yields and productivity after 1970-72. An obvious one is the effect on yields of 14-16 million hectares of land brought under crops after 1972 which formerly had been withheld from production under federal government programs. In a study done in 1969, Weisgerber estimated that yields on land held in reserve in 1966 were 80-90 percent of yields on land in crops at that time.[19] The land held in reserve accounted for much if not all of the increase in harvested cropland after 1972, and this would have tended to reduce yields in 1974-76 below what they otherwise would have been. The relatively small amount of reserve land involved suggests, however, that this factor could not explain the failure of yields to grow after 1970-72 at the same rate as in the preceding decade.[20]

Bad weather in the Corn Belt and Plains states explains much of the drop in yields and productivity in 1974 from 1973, and generally good weather no doubt explains much of the increase in yields and productivity in 1975. Dry weather and in some areas unseasonable rains reduced yields of wheat, sorghum and oats in 1976, but in major corn growing areas weather conditions were good to excellent except in the western and northern corn belt where

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[19] Weisgerber, Productivity of Diverted Cropland.

[20] Calculations assuming that yields on land harvested in 1970-72 increased at the same rate as in the 1960s and that yields on land brought under crops after 1972 were 85 percent of those on land harvested in 1970-72 indicate that, under these assumptions, the lower yields on the additional land would account for 47 percent of the difference between the observed growth of yields and the growth which would have occurred had there been no slowdown in growth on previously harvested land.

Table 14. Yields for Principal Crops (Metric Tons per Hectare) and Total Productivity in U.S. Agriculture[a]

A.

	1970	1971	1972	1973	1974	1975	1976
Corn	4.54	5.53	6.09	5.73	4.47	5.41	5.48
Grain sorghum	3.16	3.37	3.80	3.68	2.84	3.08	3.05
Wheat	2.08	2.28	2.20	2.13	1.84	2.06	2.03
Soybeans	1.80	1.85	1.87	1.86	1.56	1.94	1.72
Yield index, all crops	104	112	115	115	103	113	112
Total productivity index	101	110	109	110	107	113	113

B.

	Average Annual Percent Rates of Increase		
Yields of:	1950-52 to 1960-62	1960-62 to 1970-72	1970-72 to 1975-76
Corn	4.4%	3.6%	0.3%
Grain sorghum	5.1	5.2	-2.7
Wheat	3.9	2.7	-1.4
Soybeans	1.4	1.2	-0.1
Yield index, all crops	2.7	1.8	0.4
Total productivity index	2.5	1.3	1.0

[a]For the indexes, 1967 = 100. The 1976 index figures are preliminary.

Sources: Yields prior to 1976 from USDA, Agricultural Statistics 1976. Yields for 1976 from USDA, Crop Production. Yields in these sources are in bushels per acre. One metric ton equals 36.74 bushels of wheat or soybeans and 39.37 bushels of corn or sorghum. One hectare equals 2.471 acres. Indexes from Economic Report of the President 1977, except the crop yield index for 1976 is from USDA, Agricultural Outlook, March 1977.

hot, dry conditions reduced yields from earlier forecasts. Record corn yields were achieved in nineteen states, although the national average yield was well below the record established in 1972.[21]

Average fertilizer consumption per hectare of harvested cropland was unchanged from 1970-72 to 1975/76, while between 1960-62 and 1970-72 per hectare consumption increased at an annual rate of 8.2 percent. This decline in the rate of increase in fertilizer consumption per hectare in part reflected the fast run-up in prices of fertilizer in 1974 and early 1975, and must account in part for the behavior of crop yields so far in the 1970 relative to the previous decade. Is it significant, however, that total fertilizer consumption and consumption per hectare of harvested land rose by 15 percent from 1975 to 1976 but crop yields declined slightly.[22]

The relation between increases in yields and fertilizer consumption per hectare in the 1960s and 1970s also is consistent with the hypothesis that by the early 1970s the marginal productivity of fertilizer on American farms had declined sharply. In this case demand for fertilizer would have been more sensitive to any given increase in its price than before. We have not explored this hypothesis in depth, but it is supported by a study by the National Academy of Sciences of agricultural productivity in the United States in this period.[23] The study reviews the experience of the

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[21]USDA, Crop Production, pp. A9-A11.

[22]Fertilizer consumption and harvested land for 1960-75 are from Changes in Farm Production. Fertilizer consumption in 1976 is from Agricultural Outlook, December 1976, p. 10; harvested land in 1976 is from Economic Report of the President 1977. For crop yields in 1976 see table 14-A.

[23]National Academy of Sciences, Agricultural Production Efficiency.

United States agriculture with respect to yields and total productivity in the post-war period, noting the pattern of rapidly increasing yields and total productivity early in the period followed by sharply reduced growth by the early 1970s. It implicitly argues that wresting higher yields from the technology which produced these massive gains in yields and productivity--genetic manipulation and hybridization, improved cultivation practices such as planting and pruning for maximum leaf area, elimination of severe weed competition, improved insect control, and increased use of fertilizer and farm machinery--likely will be increasingly difficult in the balance of the 1970s and 1980s. The argument implicitly hypothesizes that technological change in agriculture is a process permitting the tapping of an increasing proportion of the biological yield potential of plants and animals. The capacity of any particular technology to do this is limited, however, and the Academy's study argues, in effect, that the slower growth in yields and total productivity evident by the early 1970s indicates that those limits were being approached by the technology on which American farmers then depended.[24]

This argument suggests that productivity effects strongly reinforced price effects after 1972 in favoring land-using relative to land-conserving technologies. The argument has important implications for the quantity and pattern of resources used by American farmers in the future, and we return to it when we consider the future situation.

Policy. The large increase in U.S. exports in 1973 prompted the federal government to modify its land diversion programs to permit more land to be brought under crops, and in 1974 these programs were abolished. This change

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[24]This is our interpretation of the argument in the National Academy's study. It is nowhere stated in precisely these terms.

in policy, of course, increased the relative attractiveness of land-using technologies.

Policies to protect the environment against certain pesticides may have tended in the same direction, but this tendency probably was weak. As noted above, in mid-1972 the EPA suspended all uses of DDT except in special localized circumstances. In 1974 and 1975 most uses of aldrin, dieldrin, chlorodane and heptachlor also were suspended. These five chemicals accounted for 15 percent of all synthetic organic insecticides used by American farmers in 1971.[25] However, use of the two most important, DDT and aldrin, already was declining rapidly before the EPA's action against them, in large part because the build-up of genetic resistance by insects had markedly reduced their effectiveness.[26] Thus, with respect to these insecticides, the EPA's action simply reinforced a trend that was already under way.

Patterns of Resource Use. The net effect of the price, productivity, and policy changes after 1972 was to encourage a relative shift from land-conserving to land-using technologies. This shift is clearly reflected in changes in the pattern of resource use. The long decline in the amount of harvested cropland was reversed, 136 million hectares being harvested in 1975 and 1976 compared with 119 million in 1972. Not since 1955 had so many hectares been harvested. The marked slowdown in the rate of increase

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[25] Andrilenas, Farmers' Use of Pesticides in 1971: Quantities.

[26] According to Andrilenas, use of the five insecticides declined from 20.2 million kilos in 1966 to 11.7 million kilos in 1971. Total consumption of synthetic organic insecticides increased from 64.8 million kilos to 75.5 million kilos in this period.

The argument that increasing insect resistance reduced the effectiveness of DDT and aldrin is in National Academy of Sciences, Pest Control, vol 1, p. 235.

of fertilizer consumption per hectare already has been noted. The quantity of purchased inputs, which per hundred million hectares of harvested cropland had risen 70 percent from 1950-52 to 1970-72, fell 11 percent from 1970-72 to 1974/75.

Technological Choices: The Future Situation

In attempting to assess the technological choices American farmers will make in the future, it is essential to consider whether the conditions affecting the behavior of prices of land and non-land inputs and crop yields since 1972 will persist. If non-land input prices stay high relative to prices of land and additional gains in yields from available technologies hard to extract, then for any given increase in farm output, farmers will continue to favor land-using technologies, as they have since 1972. If non-land input prices fall relative to land prices and potential for additional yields in fact is high, then choices will be weighted more heavily toward land-conserving technologies.

Prices of Yield-Increasing Inputs. Speculation about the future course of prices and yields is always subject to uncertainty, and the further ahead one attempts to look, the murkier the view. The behavior of fertilizer prices clearly is of key importance. By the fall of 1976 fertilizer prices had fallen 25-30 percent from the peak reached in the spring of 1975, but still were about 75 percent above the average price for 1972.[27] The value of farm real estate per acre increased 25 percent from the spring of 1975 to the fall of 1976.[28] Consequently, changes in the price of fertilizer

[27] USDA, Agricultural Outlook, December 1976, p. 11.

[28] Economic Report of the President 1977.

relative to the value of land would have encouraged land-conserving technologies, and in fact, fertilizer consumption per acre rose sharply in 1976 from 1975.

With respect to the longer term, a study by Reidinger[29] of the world situation for fertilizer suggests that additions to capacity in the second half of the 1970s will be enough to keep pace with demand. This would tend to stabilize prices at around the levels of 1976, other things the same. One of the important "other things," however, is energy, particularly fossil fuels, a key input in production of nitrogen fertilizer. The long-term trend of the price of fossil fuels is rising, which will put upward pressure on the price of nitrogen fertilizer.

Of course, energy also is an important input in pumping groundwater and driving tractors and other farm machinery. The price of all forms of energy will be strongly influenced for years ahead by the cartel of oil-exporting nations (OPEC). While the cohesiveness of OPEC showed signs of strain late in 1976, with Saudi Arabia refusing to go along with the 15 percent price increase in 1977 wanted by other members, there was no evidence of imminent break-up of the cartel. With continued recovery of the industrialized countries from the recession of 1974/75, the demand for OPEC oil likely will rise steadily, creating conditions favorable to further increases in oil prices.

A continued rise in the price of energy will tend to make irrigation more expensive relative to dryland farming, at least in areas where irrigation is from groundwater. There also are other forces which are likely to

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[29] Reidinger, World Fertilizer Review.

constrain the growth of irrigated agriculture. Declining groundwater stocks and the increasing competition for water from urbanization and energy development threaten not only the expansion but also the continuation of former levels of irrigation in parts of the west. In the southern High Plains of Texas the total land under irrigation has been declining since 1964 as a result of the falling water tables, and in many states urban growth already has resulted in the transfer of water rights from agricultural to urban uses. Since continued urban growth seems assured and the marginal value of water in these uses is considerably higher than in agriculture, additional transfers can be anticipated.

The transport of massive quantities of western coal as a slurry through pipelines to power stations, a concept under active consideration, would require large amounts of water presently used for irrigation. Coal gasification and the production of oil from shale also are water-intensive activities being considered in the western states. Although the costs of both these processes are high compared to conventional fuels, conventional energy sources are insufficient to meet future demand even at much higher prices. Thus, with future increases in fossil fuel prices or breakthrough in the technology of coal gasification or oil shale production, the transfer of sizable quantities of water from agriculture to the development of these energy resources might become profitable.

Another force likely to increase the cost of irrigation is the slowdown if not termination of new public investment in large irrigation projects. The Carter Administration has challenged the traditional system of subsidizing water projects and placed in doubt the future of numerous projects already under construction. Regardless of its impact on existing projects,

the Administration's stand is likely to subject future water projects to more critical review and may be a portent that the days of big public irrigation projects in the West are approaching an end.

On balance, our judgment is that the prices of key inputs to land-conserving technologies--fertilizer, energy and water--are likely to rise over the next decade or so from the levels of 1976. Whether they will rise faster than the price of farmland, however, is quite uncertain, for reasons developed in the next section.

Prices of Land. The projections given below (tables 15 and 16) indicate that the demand for additional cropland varies widely, depending upon the behavior of yields and the growth of demand for crops. The effect of these various levels of demand on the price of farmland will, of course, depend importantly on the supply of such land. A study by the Soil Conservation Service (SCS) showed that in 1975 there were 162 million hectares of cropland in the United States.[30] In 1975 and 1976, 136 million hectares of cropland were harvested; in addition crop failure, land in fallow, pasture, or unavoidably idle accounted for roughly 25 million hectares. These 25 million hectares are about the minimum required each year to accommodate these other uses of cropland.[31] Consequently, it appears that in 1975 and 1976 the supply of available cropland was fully utilized. In this case, any increase in the demand for cropland would require that land now in other uses be converted to cropland.

The SCS study referred to above shows that in 1975 there were

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[30] Soil Conservation Service, "Potential Cropland Study."

[31] Information provided by Dr. Orville Krause, land use specialist, USDA.

Table 15. Production, Yields, and Land Harvested, Grains and Soybeans, United States, 1975/76 Average and 1985 Baseline

	1975/76 Average			1985 Baseline Production				
				Land-conserving technologies				Land-using technologies
	Production (millions metric tons)	Land (millions hectares)	Yields	Production (millions metric tons)	Land (millions hectares)	Yields	Average annual % increase in yields	Land (millions hectares)
Wheat	58.0	28.4	2.04	58.4	23.4	2.5	2.2	28.5
Feed grains	186.0	42.8	4.35	227.2	42.1	5.4	2.3	52.2
Corn	150.2	27.9	5.38	177.8	26.5	6.7	2.3	33.0
Soybeans	37.8	20.9	1.81	57.8	28.9	2.0	1.1	31.9
All other crops		43.9			44.7			46.5
Total crops		136.0			139.1			159.1

Sources: 1975/76 is the average for those two years and is from USDA, Agricultural Outlook, December, 1976. Projections of production and yields with land-conserving technologies for grains and soybeans are from USDA, Foreign Demand and Competition Division. The derivation of the projections of land in all other crops with land-conserving technologies is described in footnote 37.

Note: The projections of land with land-using technologies assume no increase in yields from 1975/76.

Table 16. Production, Yields, and Land Harvested, Grains and Soybeans, United States, 1985 High-Demand Situation

	Land-conserving technologies				Land-using technologies
	Production (millions metric tons)	Land (millions hectares)	Yields	Average Annual % increase in yields[a]	Land (millions hectares)
Wheat	74.4	31.0	2.4	1.7	36.3
Feed grains	269.4	51.8	5.2	1.9	61.9
Corn	207.8	32.5	6.4	1.8	38.6
Soybeans	63.2	31.6	2.0	1.1	34.9
All other crops		46.9			49.2
Total crops		161.3			182.3

[a]From 1975/76.

Source: Production and yields from USDA, Foreign Demand and Competition Division.

Note: The projections of land with land-using technologies assume no increase in yields from 1975/76.

31.7 million hectares of so-called "high potential" land in other uses which could be converted economically to cropland, given commodity prices, development costs and production costs prevailing in 1974. Tables 15 and 16 indicate that this would permit accommodation of all but the highest projection of harvested cropland, suggesting that the supply of potential cropland is ample relative to all but the highest projected demand for it.

The conclusion may be deceiving, however, if it is taken to mean that the demand for additional cropland could be accommodated with little if any effect on the price of land. The fact that the "potential" cropland is described as available under economic conditions prevailing in 1974 suggests that on average it is economically inferior to land in crops in 1975 and 1976. Crop prices received by farmers in 1974 were the highest in 45 years, 108.7 percent above the average for 1970-72.[32] By 1976, crop prices had declined by 12 percent from 1974, but prices paid by farmers for production items had increased by 18 percent.[33] Consequently, the ratio of crop prices received to production prices paid fell by 25 percent from 1974 to 1976. Land which could be economically converted to crops only at price relations prevailing in 1974 would not be convertible in 1976.[34] This suggests that as the demand for more cropland presses on the potentially available supply of economically marginal land, land rents will rise in the

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[32] Economic Report of the President 1977.

[33] Ibid.

[34] The SCS study does not assert that the high potential land could be converted only under cost and price conditions of 1974. It says, rather, that land of the sort classified as having high potential was converted to crops in 1974. Conceivably some of that land would have been converted even if price conditions in 1974 had been less favorable to crops. Much of the converted land, however, had earlier been in reserve and, as indicated in the study by Weisgerber, the land held in reserve prior to 1973 was less productive than land then in crops.

classical Ricardian sense, forcing land prices up.

Cropland prices likely will rise also because of growing competitive uses for land. The SCS study showed that between 1967 and 1975 there was a net decline of 12.5 million hectares of cropland in the United States. About two-thirds of the decrease was attributable to the net conversion of cropland to range and pasture, the rest to conversion to forest land, urban, and miscellaneous uses. The SCS study does not analyze the reasons for these switches in land use. However, there is no apparent reason to believe that conditions over the next decade affecting the demand for non-crop uses of land will be so different from those in the last decade as to lead to significant slowing in the growth of demand. Urban demands for land, for example, are almost sure to increase. While the amount of land converted to urban uses likely will be small--between 1967 and 1975 it was only about 1 percent of the 1967 cropland base--the effect in raising the price of cropland may be significant.[35]

The conditions of supply of present and potential cropland thus suggest that any increase in the demand for cropland from the levels of 1975/76 will force land prices up. The amount of the increase is quite uncertain, however, in large part because of uncertainty about the future behavior of crop yields. The price of farmland, therefore, is dependent in part on yields. The analysis of the effect of land prices on farmers' choices among land-using and land-conserving technologies thus leads to analysis of the yields, or productivity of these technologies.

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[35] Clawson and Held, Soil Conservation in Perspective, pp. 106-108, argue that in the post-war period conversion of rural land to urban uses in the United States pushed farmland prices up sharply in the areas directly affected and that these effects tended to spread to other areas.

Productivity. Assessment of trends in the productivity of alternate technologies is strongly influenced by one's assessment of the behavior of crop yields since the early 1970s. If one believes the decline in yields reflects temporary phenomena of weather, bringing in less fertile land, and the high price of fertilizers, then one would expect yields to soon begin to rise again, although perhaps not at the high rates of the 1950s and 1960s. This assessment points to the conclusion that productivity considerations would once again favor land-conserving technologies.

If, however, one believes that in addition to the above factors, the behavior of yields since the early 1970s also was strongly influenced by the using up of the productivity potential of the land-conserving technologies so widely adopted in the post-war period, then one would expect productivity considerations to favor land-using technologies, unless new high-yield technologies are developed to replace those now being used up.

We believe the behavior of yields and the rationale for it given by the National Academy's study of agricultural productivity provide strong support for the second hypothesis concerning yields. The Academy's study also considers the development of new, high-yield technologies that could substitute for those presently employed and concludes that none are likely to become economical in the foreseeable future.[36] Our judgment, therefore, is that over at least the next five to ten years, farmers will continue to rely on

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[36]The National Academy's study considers alternatives to chemical pesticides, improved efficiency of photosynthesis, enhanced capacity of bacteria found on root nodules of legumes, such as soybeans, to fix nitrogen, use of plant growth regulators and techniques for growing entire plants from single cells, which would increase crop productivity by shortening the generation cycle. In each case the study finds that promising work is being done but that more, much of it basic scientific research, must be done before these alternatives become economically viable on a wide scale.

the technologies now in wide use. Consequently, we expect that productivity considerations may make land-using technologies relatively more attractive in the future.

If farmers should respond to future increases in demand for crops by adopting the land-using mode, they quickly will find it necessary to convert land now in other uses to crops. For reasons given above, this likely would push up the price of land, the rise being greater the greater the increase in demand for crops and the slower the increase in yields. As land prices rise, land-conserving technologies would become more attractive, even if the potential for productivity gains from these technologies were low. Thus, while in the immediate future prices of non-land inputs and productivity considerations might favor the land-using mode, expansion along this path likely would soon generate counterpressures favoring the land-conserving mode.

There is no good basis for sorting out the effects of these various and in part conflicting influences on farmers' choices between land-using and land-conserving technologies. Accordingly, we have made two sets of projections of resource use, one representing the land-using mode of response and the other the land-conserving mode. These projections are discussed in the following section.

Projections of Resource Use

Harvested Land

These projections have been made for both the baseline situation (table 15) and the high-demand situation (table 16). The projections of harvested land for grains and soybeans were derived by dividing projected production by projected yields. For all other crops the projections of

harvested land were derived in the manner described in a footnote.[37]

Given the projections of production of grains and soybeans, the critical variable in the projections of harvested land in these crops is the projection of yields. For the land-conserving technologies the yield projections are those of the USDA's Foreign Demand and Competition Division (FDCD).[38] The FDCD does not describe these projections as reflecting land-conserving technologies. That is our label. Land-conserving technologies rely more on yield increases to produce a unit of a given crop than land-using technologies. Any given technology, therefore, will be considered land-using relative to some technologies and land-conserving relative to others. Hence, the technologies which underlie the yield increases in tables 15 and 16 are land-conserving relative to those which underlie the projections of constant yields.

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[37]The USDA's Foreign Demand and Competition Division, the source for the yield and production projections for grains and soybeans underlying tables 15 and 16, does not project production and yields for crops other than grains and soybeans. Hence it was not possible to derive projections of harvested land in these other crops in the same way as for grains and soybeans. Another USDA source, Agriculture The Third Century was used to derive projections of land harvested in other crops. This source shows both baseline and high demand projections to 1985 of total harvested land as well as harvested land in grains and soybeans. The differences between total harvested land and land in grains and soybeans gives the projections of harvested land in other crops shown in tables 15 and 16 (with land-conserving technologies).

From Agriculture The Third Century and USDA Agricultural Statistics 1976 we calculate the growth of production of "other crops" from 1975/76 to 1985 at 6 percent in the baseline situation and 12 percent in the high-demand situation. Since we assume that with land-using technologies there would be no increase in yields, the amount of land in "other" crops is projected to increase from 1975/76 to 1985 by the same percentage amount as the increase in production.

[38]USDA, Foreign Demand and Competition Division, "Alternative Futures."

The yield projections reflecting land-conserving technologies assume that the stagnation or decline of grain and soybean yields between 1970-72 and 1975/76 (see table 14) will end and that further yield increases will be achieved. The ranges of increase are not high compared with experience in the 1950s and 1960s. In fact, they can be viewed as a return to the pattern of declining rates of increase characteristic of the 1950s and 1960s. This reflects the projection technique employed at the FDCD, which relies heavily on historical trends, tempered by judgment to reflect factors not fully captured in the trend. In the present case the FDCD clearly regards the stagnation or decline of yields since 1970-72 as attributable to temporary phenomena. The argument that recent yield behavior in large part reflects the exhaustion of the yield increasing potential of the technologies now widely used is implicitly rejected. The FDCD projections must also assume that prices of land and other inputs will behave so as to favor the adoption of land-conserving technologies.

The yield projections in tables 15 and 16 corresponding to land-using technologies are by the authors. They represent a situation which could occur if in fact the yield increasing potential of currently used technologies had been exhausted and prices of land and other inputs favor land-using technologies. Of course, if these conditions should prevail, yields would not necessarily remain constant, as we have assumed. They could increase a little, or they could decline from present levels, depending upon the strength of the price and productivity conditions affecting farmers' choices among technologies. Hence the projections of constant yields are not predictions. Rather, they are intended to represent an outcome, albeit perhaps an extreme one, which could occur if price and productivity conditions

favor more land-using technologies than those underlying the projections of rising yields.

The projected increase in the amount of harvested land (relative to 1975/76) range from 3.1 million hectares for the baseline situation with land-conserving technologies to 46.3 million hectares for the high production situation with land-using technologies. The lowest projected increase probably could be accommodated with relatively little impact on the price of farmland. Any of the others, however, likely would cause land prices to rise. As noted above, farmers would respond to rising land prices by moving toward the land-conserving mode of expansion. Even this mode, however, could require substantially greater quantities of land, implying higher land prices, if the high production situation prevails.

Tables 15 and 16 suggest that the real costs of agricultural production in the United States may rise from the levels of 1975/76, except perhaps in the baseline situation with land-conserving technologies. Conceivably, these costs could rise enough to weaken the U.S. competitive position in world markets for grains and soybeans, in which case the projections of production would turn out to be too high. This would take some of the pressure off the rise in costs, but the implications for the United States balance of payments are sobering. Higher costs of production also would increase real prices of food to United States' consumers. In short, the high demand situation may significantly increase the pressure on the capacity of American agriculture to produce.

Fertilizer

The projections of fertilizer corresponding to land-conserving and land-using technologies are shown in table 17. The argument underlying the

projections is simple. If the conditions favoring land-using technologies--high prices and low marginal productivity of fertilizer and other inputs relative to land--should continue, then we would expect little if any additional growth in the amounts of fertilizer used per hectare. The period 1970-72 to 1976 is the guide for changes in per hectare use under these conditions.

If the conditions which favored land-conserving technologies in the years up to 1972 should prevail once again, then we would expect faster growth in per hectare use of fertilizer than in the period since 1972. For reasons given in the appendix, experience in the years 1969-1972 is taken as a guide to how per hectare consumption might increase under conditions favoring land-conserving technologies. The projections of total fertilizer consumption in table 17 are the products of use per hectare and the projections of hectares are shown in tables 15 and 16.

Table 17. Fertilizer Use in U.S. Agriculture*

1976		1985					
				Total (millions metric tons)			
				Baseline production		High production	
Per hectare (kilos)	Total (millions metric tons)	Per hectare (kilos) LCTs	LUTs	LCTs	LUTs	LCTs	LUTs
135.1	18.3	163.0	142.3	22.7	22.6	26.3	25.9

*Nutrient value of nitrogen, phosphorous and potassium.

LCTs and LUTs mean land-conserving technologies and land-using technologies.

Sources and procedures: see appendix, this chapter.

Pesticides

Table 18 shows consumption of herbicides, insecticides, fungicides, and miscellaneous pesticides per hectare of harvested cropland in 1966 and 1971. Tables 19 and 20 show total pesticide consumption in 1971 and projections to 1985 with baseline and high-demand production respectively. The assumptions and procedures underlying the projections are given in the appendix.

Table 18. Consumption of Pesticides* in the United States, 1966 and 1971 (kilos of active ingredients per hectare)

	Insecticides		Herbicides		Fungicides		Miscellaneous pesticides	
	1966	1971	1966	1971	1966	1971	1966	1971
Cotton	7.59	7.15	0.76	1.91	0.04	0.03	1.67	1.83
Corn	0.46	0.45	0.91	1.77	a	a	a	a
Wheat	a	a	0.19	0.27	a	a	a	a
Soybeans	0.10	0.15	0.31	0.95	a	a	a	a
Sorghum	a	a	0.35	0.79	a	a	a	a
Peanuts	a	a	2.29	3.23	0.87	3.40	a	a
Fruits & nuts	a	3.46	a	0.66	a	5.71	a	a
All crops	0.53	0.57	0.43	0.83	0.12	0.15	0.18	0.17
All crops except cotton	0.29	0.31	0.42	0.79	0.12	0.15	0.13	0.10

*Excludes sulphur and petroleum.

[a]Included in all crops.

Sources: Andrilenas, Farmers' Use of Pesticides in 1971--Quantities and Farmers' Use of Pesticides in 1971--Extent of Crop Use.

Table 19. Pesticide Consumption* on Crops in the United States

	Kilos per harvested hectare			Total consumption (millions kilos)			
		1985 with				Baseline production in 1985 with	
	1971	Land-conserving technologies	Land-using technologies	1966	1971	Land-conserving technologies	Land-using technologies
Insecticides	0.57	0.56	0.52	62.5	70.1	78.2	82.2
Herbicides	0.83	1.66	1.26	51.1	102.6	230.9	200.5
Fungicides	0.15	0.15	0.15	13.9	18.0	21.4	23.4
Miscellaneous pesticides	0.17	0.17	0.14	21.7	21.0	23.1	22.5
Total	1.72	2.54	2.07	149.2	211.7	353.6	328.6

*Active ingredients. Excludes sulphur and petroleum.

Sources and procedures: 1971 from Andrilenas, Farmers' Use of Pesticides in 1971--Quantities. For projections, see the appendix.

Table 20. 1985 Crop Pesticide Consumption*, United States, High-Demand Production

	Millions kilos	
	Land-conserving technologies	Land-using technologies
Insecticides	90.3	94.8
Herbicides	267.8	229.7
Fungicides	24.2	27.3
Miscellaneous pesticides	27.4	25.5
Total	409.7	377.3

*Active ingredients. Excludes sulphur and petroleum.

Sources and procedures: See appendix, this chapter.

Irrigation

Irrigation is a highly land-conserving technology. In the early 1970s, the average value of agricultural output on harvested lands was nearly 2.8 times higher with irrigation than without, and irrigation accounted for nearly 27 percent of the value of production on a little less than 12 percent of the harvested land.[39] Both the direct impacts of controlled water receipts and the complementarity between water and the other principal yield-increasing inputs such as fertilizer and pesticides contributed to these higher yields on irrigated lands.

[39]These calculations are based on data provided by Dallas Lea, ERS, USDA, in March 1977. All of the value of production data as well as the acreage data for the seventeen western states, Arkansas, Louisiana, and Florida are 1971-73 acreages based on data of the Statistical Reporting Service. The acreage data for the other twenty-eight states are from the 1969 Census of Agriculture.

The 90 percent increase in irrigated land from 1944 to 1969 contributed significantly to the overall rise in agricultural yields and the ability of U.S. farmers to expand production on a declining land base. Future yield increases as well as the pressures on the land base stemming from a given level of production will continue to depend significantly on the changing role of irrigation. While we have made no projections of irrigated acreage, all available projections suggest that the future growth of irrigated agriculture in the western states and in the nation as a whole will be well below the growth rates achieved during the decades of the forties, fifties, and sixties. A decline in the rate of growth of irrigated acreage is consistent with the relatively low growth between 1969 and 1974 as well as with the conclusions of our earlier discussion regarding the impacts of declining groundwater stocks, energy costs, government policies, and nonagricultural demands for water on irrigation.

Conclusions

Tables 15-20 indicate that, under the assumed conditions, American farmers would employ more land, fertilizers and pesticides in crop production in 1985 than they did in the early- and mid-1970s. The projected increases in demand for these resources of course depend upon the assumed increase in crop demand and the kind of technology employed to meet it. Baseline crop demand with land-conserving technologies would require relatively small amounts of additional resources. Each of the other three situations considered, however, would require substantially greater resources, particularly land and pesticides.

Any increase in the amounts of harvested land, fertilizers and pesticides may increase the threat of environmental damage. The next chapter considers this possibility with respect to the above projections of these resources.

Appendix

Projections of Pesticide and Fertilizer Consumption

We have seen no convincing models for projecting either pesticides or fertilizers. Consequently, the projections for both sorts of materials are wholly our own. It cannot be emphasized too strongly that the projections are very rough. They reflect our best judgment of factors affecting use of these materials, but they undoubtedly are subject to wide margins of error.

Pesticides

Given the projections of harvested cropland, the key to projections of total pesticide consumption is projections of consumption per hectare. These projections are then multiplied by the projections of harvested land (tables 15 and 16) to derive projections to total consumption.

Land-Conserving Technologies. Table 18 shows that per hectare consumption of insecticides on cotton was far greater than on all other crops, and that it declined by 6 percent between 1966 and 1971. We have seen no explanation of this decline and have assumed that it will not continue to 1985. If the decline was not a transitory phenomenon but reflected a change in pest management technology, then our assumption likely would overstate insecticide use on cotton in 1985.

Smith and coauthors project cotton land in 1985 at 4.2 million hectares in the baseline situation.[40] Our projection of pesticide use on cotton,

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[40] Projections of the U.S. Farm Subsector.

therefore, is 30.0 million kilos (4.2 million hectares times 7.15 kilos per hectare, the 1971 use).

Table 18 shows that per hectare use of insecticides on all crops except cotton rose from 0.29 kilos in 1966 to 0.31 kilos in 1971, an annual rate of 1.3 percent. If this rate were maintained from 1971 to 1985, pesticide use per hectare of all crops except cotton would grow by 20.5 percent. We have assumed, however, that growth will slow to 15 percent, the net effect of several conflicting trends. The number of farmers who had not yet begun to use insecticides or who used them in less than optimum amounts must have been much less in 1971 than in 1966. Hence the potential for increased per hectare use from this source was reduced. Offsetting this to some extent, however, is the trend toward substitution of minimum tillage for conventional (mold board plow) tillage. Because minimum tillage leaves crop stubble on the field, it creates better conditions for insects than conventional tillage. Hence the relative spread of minimum tillage should increase the need for insecticides per hectare.

Insecticide use on crops other than cotton is projected to be 0.357 kilos per hectare in 1985 (1.15 times 0.31 kilos per hectare in 1971). Total use on these crops, therefore, would be 48.2 million kilos in 1985 (0.357 times 139.1 million total harvested hectares minus 4.2 million hectares in cotton--see table 15). Total projected insecticide use of 78.2 million kilos (table 19) is the sum of that used in cotton (30.0 million kilos) and that used on other crops (48.2 million).

Table 18 shows that while per hectare use of herbicides is higher on cotton and corn than on other crops, the disparity is not as great as it is between cotton and all other crops with respect to insecticides. Hence we have simply projected herbicide use per hectare for all crops.

Per hectare use of herbicides on crops almost doubled between 1966 and 1971, an annual rate of increase of almost 14 percent. We have seen no explanation of this rapid rate of growth in herbicide use, but the spread of minimum and no tillage must be partly responsible. With these techniques weed control by plowing is virtually eliminated, creating a larger need for herbicide per hectare. According to the "No-Till Farmer," 10.6 million hectares of land were minimum tilled in 1972 and no-tilled land was 1.3 million hectares. Figures for 1966 are not available, but it is known that these tillage techniques were spreading rapidly before 1972.

The "No-Till Farmer" states that minimum and no-tilled land increased from 11.9 million hectares in 1972 to 24.2 million hectares in 1976, suggesting that herbicide use per hectare and in total continued to increase rapidly after 1971. The "No-Till Farmer" asserts that the USDA has projected continued rapid growth for these tillage techniques to the end of the century, at which time they would be employed on 95 percent of U.S. cropland. The outlook, therefore, is for continued rapid spread of these techniques, although the rate of spread must necessarily slow since, if the "No-Till Farmer" figures for 1976 are correct, 18 percent of harvested land already was minimum or no-tilled that year.[41]

Given the prospect that minimum and no-tillage techniques will continue to spread, it is likely that use of herbicides per hectare also will continue to rise, although at a slower annual rate than between 1966 and 1971. We have assumed that the rate will fall from 14 percent annually to 5 percent. In this event, per hectare use would rise from 0.83 kilos in 1971 (table 18)

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[41]The "No-Till Farmer" figures for 1976 are considerably higher than those cited in the next chapter, page 187. For present purposes, however, the difference is not significant.

to 1.66 kilos in 1985, and total consumption of herbicides would be 230.9 million kilos in that year (table 19).

In 1971, fungicides accounted for 8.5 percent of all pesticides used on crops in the United States.[42] Eighty-five percent of these fungicides were applied to fruits, nuts (including peanuts), and vegetables. While 1966 data on a per hectare basis are not available for fruits, nuts, and vegetables, Adrilenas' data indicate that per hectare use was less than in 1971. Per hectare use of fungicides on peanuts increased sharply from 1966 to 1971 (table 18). We have seen no explanation of the increasing use per hectare of fungicides on these crops between 1966 and 1971, but we assume the increase will slow drastically to 10 percent from 1971 to 1985. Smith and coauthors project an 8 percent increase in land in these crops from 1970-72 to 1985.[43] Accordingly, we project total fungicide use in 1985 to be 19 percent above the level of 1971 (1.10 times 1.08; table 19). This may be conservative, judging from the fast rate of growth in consumption of these materials from 1966 to 1971. However, even if total fungicide use were to double between 1971 and 1985, the effect on the projection of total pesticide consumption would be small because fungicides are such a small percentage of the total.

Adrilenas' data indicate that miscellaneous pesticides were 10 percent of total pesticide consumption in 1971.[44] Eighty-three percent of

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[42] Andrilenas, Farmers' Use of Pesticides in 1971--Quantities.

[43] Smith and others, Projections of the U.S. Farm Subsector.

[44] Andrilenas, Farmers' Use of Pesticides in 1971--Quantities.

miscellaneous pesticides that year were used on cotton, vegetables, and tobacco. Per acre use on these crops apparently rose from 1966 to 1971, with a particularly sharp increase for tobacco. We assume that per acre use of miscellaneous pesticides will increase an additional 10 percent from 1971 to 1985. Land devoted to these crops is not expected to increase by 1985.[45] Hence our projection is that consumption of miscellaneous pesticides will grow by 10 percent from 1971 to 1985 (table 19). As in the case of fungicides, this projection could be wrong by a large amount without significantly affecting the projection of total pesticide consumption.

Land-Using Technologies. Since these technologies employ fewer nonland inputs per unit of land to achieve a given increase in output than land-conserving technologies, our projections of pesticide use per hectare for land-using technologies are less than the projections for land-conserving technologies (table 19). There is little basis, however, for judging precisely how much lower they would be. We have assumed that per hectare use of insecticides on cotton will decline about 10 percent to 6.65 kilos by 1985 (from 7.15 kilos in 1971) and that per hectare use of insecticides on all other crops will increase by 5 percent in this period (instead of the 15 percent assumed for land-conserving technologies). Smith and coauthors project about a 15 percent increase in cotton yields between 1975/76 and 1985 and that harvested cotton land will be 4.2 million hectares in the latter year.[46] If there is no increase in yields, however, 15 percent more hectares of cotton land would have to be harvested

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[45] Smith and others, Projections of the U.S. Farm Subsector.

[46] Ibid.

to meet 1985 production. Harvested cotton land, therefore, would be 4.8 million hectares and total consumption of insecticides on cotton would be 31.9 million kilos in 1985 (4.8 million hectares times 6.65 kilos per hectare). All other harvested land would be 154.3 million hectares (159.1 million total hectares from table 15 less 4.8 million hectares in cotton) and insecticide consumption on that land would be 50.3 million kilos (154.3 million hectares times 0.326 kilos per hectare, a 5 percent increase from the 0.31 kilos per hectare in 1971). Total insecticide use in 1985, therefore, would be 82.2 million kilos and use per hectare of all harvested land would be 0.52 kilos (table 19).

Under these assumptions, the percentage increase in number of hectares required for baseline production with no increase in yields would be greater than the percentage decline in insecticide use per hectare, resulting in more total insecticide use with land-using technologies than with land-conserving technologies. This conclusion, of course, reflects the particular assumptions we have made, and others are equally plausible. However, even if per hectare consumption of insecticides on cotton declined from 1971 to 1985 at the same rate as from 1966 to 1971 (0.09 kilos per year), reaching 5.80 kilos in 1985, and per hectare consumption of insecticides on all other crops remained at the 1971 level (instead of increasing 5 percent), total consumption of insecticides in 1985 would be 74.9 million kilos, only 3.3 million kilos less than the projection with land-conserving technologies.

The projected growth of herbicide use per hectare was 5 percent annually with land-conserving technologies. There is no firm basis for judging how much less the growth rate would be with land-using technologies. We assume it would be 3.0 percent annually. In this case, use of herbicides per hectare would rise from 0.83 kilos in 1971 to 1.26 kilos in 1985, and total

herbicide use would rise to 200.5 million kilos, 13 percent less than projected for land-conserving technologies (table 19).

The projections of fungicide use per hectare with land-conserving technologies assume an increase of 10 percent from 1971 to 1985. We assume that with land-using technologies there will be no increase in use per hectare. Projections by Smith and coauthors of yields of vegetables, fruits, and nuts, the crops on which most fungicides are used, imply an increase in yields of about 20 percent from 1970-72 to 1985 and of land on these crops of about 8 percent. These projections, therefore, imply a 30 percent increase in production of these crops from 1970-72 to 1985. Since the land-using technologies are assumed to leave yields unchanged, we project a 30 percent increase in the amount of land in crops on which fungicides are used. Since use per hectare is assumed constant, total fungicide use is projected to increase by 30 percent from 1971 to 1985 with land-using technologies.

We assumed that with land-conserving technologies per hectare use of miscellaneous pesticides on cotton, tobacco, and vegetables (83 percent of all such pesticides in 1971) would increase by 10 percent from 1971 to 1985. We assume that with land-using technologies per hectare use of these pesticides would remain unchanged. Since yields also are assumed not to change, land in these crops would increase by the same percent as production. The weighted average increase would be about 7 percent.[47] This, therefore, is the projected increase in total use of miscellaneous pesticides from 1971 to 1985 with land-using technologies.

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[47] Ibid.

We have assumed that per hectare use of the various pesticides would be the same for the baseline and high-demand situations. We perhaps should have assumed higher use per hectare in the high-demand situation since much of the additional land required in that situation likely would be more vulnerable to weed, insect and other pest infestation than land used in the baseline situation. However, there is no basis for making this adjustment so we did not attempt it. Accordingly the projections of pesticide consumption in the high-demand situation for land-using and land-conserving technologies were made by multiplying the projected consumption per hectare of each pesticide (table 19 by the projections of total harvested land in the high-demand situation (table 16). The results are shown in table 20.

Concluding Comment. The crudity of these projections needs no emphasis. For what it is worth the projections on a per hectare basis corresponding to land-conserving technologies are similar to projections made by the USDA (table 21). The assumptions underlying the USDA projections differ in some details from ours but agree in giving considerable weight to the spread of minimum tillage as a factor increasing per hectare use of insecticides and herbicides, especially the latter.

The USDA projections do not use the concepts of land-using and land-conserving technologies. However, they reflect the yield increases associated with land-conserving technologies as we have defined them. Hence the USDA projections of per hectare use of pesticides are conceptually comparable to ours.

Table 21. Projections of Pesticide Use on Crops Per Hectare of Harvested Cropland in 1985

(kilos)

	USDA[a]	This study[b]
Insecticides	0.62	0.56
Herbicides	1.59	1.66
Fungicides	0.16	0.15
Miscellaneous	0.26	0.17
	2.63	2.54

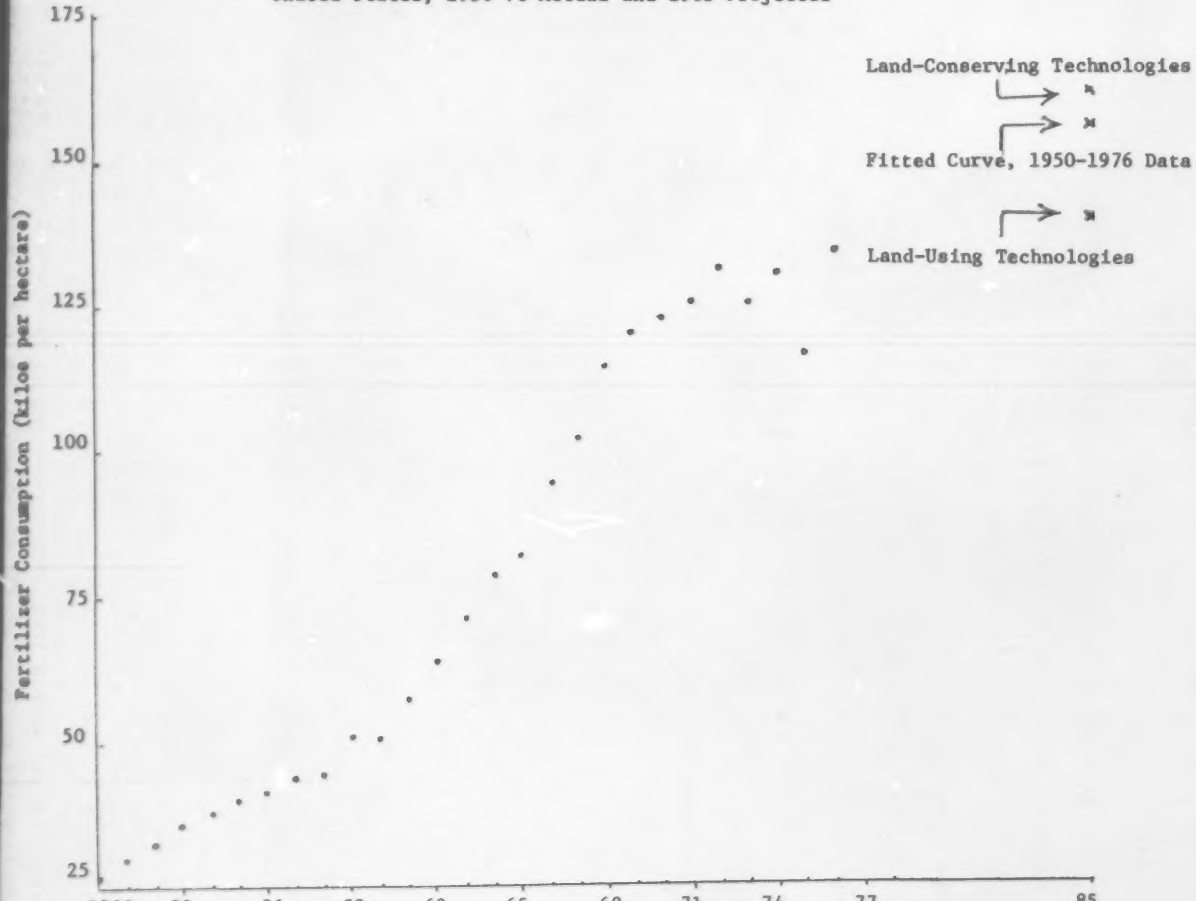
[a]Austin Fox, "Research on Projecting Agricultural Inputs." The projections given by Fox are for use of pesticides in animal production and miscellaneous farm purposes as well as for crops. We adjusted them for crop use only by the proportion of crop use to total use in 1971 and divided by 128 million hectares, the harvested land area shown in Fox's paper.

[b]Table 19, land-conserving technologies.

Fertilizers

If the conditions favoring land-conserving technologies should prevail in the period to 1985, then we would expect fertilizer use per hectare to rise faster (or fall less) than it would if conditions should favor land-using technologies. This tells us that one of the projections ought to be higher than the other, but little else. Moreover, we know of no formal projection technique which would help. Use of an equation fitted to historical data on fertilizer use per hectare is unattractive because of evidence that the relation may have changed radically since the early 1970s. This is evident in figure 2, and is the main thrust of the argument in the text that the marginal productivity of fertilizers may have fallen so low by the

Figure 2. Fertilizer Consumption (kilos per hectare) in the United States, 1950-76 Actual and 1985 Projected



early 1970s as to make demand more sensitive than earlier to increases in fertilizer prices.[48]

Our projections of per hectare consumption of fertilizers are arbitrary in the sense that we could easily have used different numbers consistent with the principle that the projection for land-conserving technologies should be higher than the one for land-using technologies. However, the projections actually adopted bear a sensible relationship to the historical behavior of the data (figure 2), and in this sense they are not arbitrary. For land-conserving technologies we have assumed that the data from 1969 to 1972 reflect the beginning of a period in which consumption per hectare would increase at a diminishing absolute rate. The average annual increase from 1969 to 1972 was 3.9 kilos per hectare. We have assumed the increase from 1976 to 1977 would also be 3.9 kilos and that from 1977 to 1985 the increase would diminish by 0.2 kilos per year. This gives a 1985 figure of 163.0 kilos per hectare. (See figure 2 and table 17.)

For land-using technologies we assume that the experience from 1972 to 1976 would represent the period 1976-1985. From 1972 to 1976 fertilizer consumption per hectare increased by 0.8 kilos per year. Projecting this rate of increase to 1985 gives 142.3 kilos for that year. (See figure 2 and table 17.)

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[48]We computed a logistics curve for the data shown in figure 2 and got a good fit. However, the data from 1950 to 1972 reflect conditions highly favorable to land-conserving technologies while from 1972 to 1976 conditions favored land-using technologies. Consequently the curve fitted to the data for 1950 to 1976 could not reasonably be used to project fertilizer use with either land-conserving or land-using technologies. We also computed a curve for the period 1950-72, thinking to use this to project for land-conserving technologies, but could not get a good fit so we abandoned this idea.

In figure 2 we show the projection derived from the curve fitted to 1950-76 data, but as noted, we do not use it to project total fertilizer consumption.

As in the case of pesticides, we assume that per hectare consumption of fertilizers would be the same in both the baseline and high demand situations. The projections of total consumption, therefore, are the products of consumption per hectare (table 17) times total harvested hectares (tables 15 and 16). The results are shown in table 17.

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Chapter 7

ENVIRONMENTAL IMPLICATIONS FOR THE UNITED STATES OF INCREASING FOOD PRODUCTION

Introduction

Realization of the land, fertilizer, and pesticide projections in the last chapter would increase pressure on the environment in the United States, possibly to the point that new policies would be needed to deal with the resulting problems. This chapter assesses the environmental hazards that might arise and some of the policy issues likely to be considered. We make no pretense that the analysis of either hazards or policy issues is definitive. Indeed, we believe such an analysis is beyond the reach of anyone because too little is known about the nature and extent of the hazards we now face, let alone what they might be in 1985 and beyond. Nonetheless, we believe that a review of the salient features of present knowledge about the hazards is useful as a basis for speculation about their future magnitude, given the projections of quantities developed in the last chapter, and that such speculation is a first step in identifying key problems likely to require research and policy action in the future.

The chapter is in five parts. The first four discuss the present and prospective environmental hazards resulting from erosion, fertilizer, pesticides, and salinity, respectively. The fifth part considers policy issues.

Environmental Impacts of Resource Use: Erosion

The Present Situation

In terms of volume, sediment resulting from rain induced erosion is by far the single largest contributor to water pollution in the United States. Under some conditions wind erosion can be a major source of air pollution, as occurred during the "dust bowl" years of the 1930s when topsoil picked up in the Great Plains fouled the air on occasion not only in that region but in much of the eastern half of the country. Year in year out, however, the amount of soil eroded by water is vastly greater than that moved by the wind. Accordingly, the discussion here is focused on erosion by water.

It is asserted that 3.6 billion metric tons of soil are eroded annually by water in the United States, with 2.7 billion originating on agricultural and forest lands.[1] Such estimates are not based on direct measurement but rather on rough calculations from the universal soil loss equation.[2] They are subject to a wide margin of error in any year, and they would vary widely from year to year, depending upon variations in the amount, the intensity, and the geographical distribution of rainfall and in the uses to which the land is put.

The amount of gross erosion, that is, the tons of soil moved from one place to another by wind and water in any given year, in itself tells

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[1]For example, Meister, Heady, Nicol and Strohbehn, U.S. Agricultural Production.

[2]The universal soil loss equation is described in chapter 4, p. 87.

little. The important question is, what damage does it do? In the discussion of erosion in chapter 4 we pointed out that the damage is of two sorts: (1) the loss of soil productivity in the eroded areas, and (2) downstream damages from sedimentation.[3] There are no good estimates of either of these types of damages in the United States at the present time. As noted in chapter 4, the relation of productivity loss to loss of topsoil depends upon the amount of topsoil lost relative to total topsoil available, the nature of the material underlying the topsoil and land management practices. In the United States topsoil thickness varies from a few centimeters to one-half meter or more. In the Corn Belt topsoils are fifteen to forty centimeters thick.[4] Fifteen centimeters of topsoil on a hectare of land weighs roughly 2,000 metric tons. Hence rates of loss well in excess of the 2.25 to 11.2 metric tons per hectare per year thought to be consistent with indefinite maintenance of productivity could be sustained for many years before the topsoil were completely exhausted.[5] It is likely that the productivity of the land would begin to decline well before the topsoil were completely lost, but no general statements can be made about the extent of the decline per unit loss of topsoil. Much depends on the nature and depth of the material underlying the topsoil and soil management practices. If the underlying material is a thick layer of sand, clay, or rock, total loss of the topsoil would have a disasterous effect on productivity. If the material extends

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[3] As noted, wind erosion also can cause damages, but these are small by comparison with those caused by water induced erosion.

[4] Committee on Agriculture and Forestry, Conservation of the Land.

[5] These are the soil loss rates per hectare deemed acceptable by the Soil Conservation Service. At this writing we have not clarified the basis for these standards. Since there are few, if any, areas in the United States where the rate of generation of topsoil is 2.25 tons per hectare per year, let alone 11.2 tons, it is not clear how losses of this magnitude are consistent with indefinite maintenance of soil productivity.

several feet and has favorable physical and chemical properties, however, nutrients lost in topsoil can be replaced by fertilizer, and organic matter can be added by roots and crop residues in such fashion that the loss of topsoil has little effect on productivity.[6] However, the cost of production would rise because of the substitution of fertilizer for natural soil nutrients.

It is estimated that in the central Corn Belt, with average management and moderate amounts of fertilizer, land of 4 to 12 percent slope from which most topsoil has been lost has suffered a 30 percent reduction of productivity if subsoils are unfavorable and a 15 percent reduction if subsoils are favorable. With more skilled management and more fertilizer, the productivity declines are estimated at 20 percent and 10 percent, depending upon conditions of the subsoil.[7]

Such estimates are evidence that erosion exacts a cost in lost productivity, and while they suggest that in some areas the cost may be high, they provide no basis for judging the importance of the cost as a national problem. That it is not negligible, however, is suggested by the fact that at present more than one-third of the cropland in the United States suffers soil losses in excess of the amount believed consistent with maintenance of soil productivity over the long run.[8]

The downstream damages from erosion depend upon the amount of soil moved and where it is deposited. In the United States, the amount of eroded soil

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[6] Committee on Agriculture and Forestry, Conservation of the Land.

[7] Ibid.

[8] Ibid.

discharged to the oceans usually is less than one-fourth of gross erosion.[9] The other three-fourths is deposited near and far from its original place, some in other parts of farmers' fields, some at the base of nearby slopes, some in flood plains and some in stream beds and reservoirs. Some of the soil deposited does little damage, and some may be beneficial, for example, that contributing to the build-up of fertile delta areas. However, that which leads to increased flooding or which shortens the life of reservoirs or clogs irrigation systems may do significant harm. As indicated above, however, there are no good estimates of the total value of these damages in the nation as a whole.[10]

Whatever the damages caused by erosion from agricultural lands at present, there is strong evidence that they increased after 1972. A survey undertaken by the Soil Conservation Service in July 1974, showed that in the Plains, Corn Belt, and Lake states soil losses to erosion on 0.47 million hectares of land converted to crops from other uses in the 1973/74 crop year ranged from 11.2 to 224 million metric tons per hectare per year. These losses were over and above the losses that might otherwise have occurred on these lands. As noted above, the Soil Conservation

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[9] Task Committee on Preparation of Sedimentation Manual, "Sediment Sources and Sediment Yields."

[10] One source (Committee on Agriculture and Forestry) asserts that dealing with the consequences of erosion costs $83 million for dredging channels and harbors, $50 million for reservoir sedimentation and flood-plain overwash, and $25 million by cities and industry for added maintenance and removal of turbidity. These costs are in addition to losses in esthetic and recreation values because of turbidity. The source does not indicate that these costs are incurred annually, although we assume that is the case. It is not stated whether the corrective measures taken reduce erosion damages to zero. If they do not, the cost figures would understate the value of the damages. The basis of the cost estimates is not given.

Service considers up to 11.2 metric tons per hectare per year an acceptable rate of loss. For the entire nation the survey showed that on 3.6 million hectares converted to crops from other uses erosion losses averaged 15.0 metric tons per hectare per year over and above losses that would have occurred under the previous use. Most of the loss occurred on land which had received inadequate conservation treatment. On these lands, losses averaged 26.9 metric tons per hectare per year.[11]

The SCS survey was of land converted to crops from other uses. It is also clear that on land already in a cropping rotation some farmers after 1972 abandoned or modified erosion control practices, such as strip cropping, in order to maximize the land devoted to crops, thus taking advantage of the high crop prices prevailing in 1973-76. While estimates of the increase in erosion caused by this change in practices are not available, it likely was significant. Erosion damages, therefore, must have risen also.

The Future Situation

The future magnitude of the erosion problem in the United States resulting from agricultural production will depend primarily upon the amount of land in crops, the location and other characteristics of that land relevant to erosion, the tillage techniques employed on the land, and farmers' incentives to adopt erosion control practices.

Table 22 summarizes information from tables 15 and 16 about amounts of harvested land in the United States. The projected amount of land with land-conserving technologies in the baseline situation is only 3.1 million

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[11]Grant, "Erosion in 1973-74."

Table 22

Land Harvested in the United States

(million hectares)

	Baseline Situation		High Demand Situation	
1975/76	LCT	LUT	LCT	LUT
136.0	139.1	159.1	161.3	182.3

Source: Tables 15 and 16. LCT means land-conserving technologies and LUT means land-using technologies.

hectares more than the land harvested in 1975/76. While even this small additional amount of land might have to come from land now in non-crop uses (probably permanent pasture or forest) which are less erosive than crop production, the total erosion problem likely would diminish from its present intensity should total harvested land increase no more than 3.1 million hectares. The principal reason for believing this is the expected spread of minimum, or conservation tillage. The basis for this expectation is dealt with at greater length below. Suffice it to say here that the economics of conservation tillage seem to favor its adoption on a wider scale than at present, and it produces significantly less erosion than conventional tillage. Thus, whatever might be the erosion on the small amount of additional cropland, erosion from land now conventionally tilled would decline with the switch to conservation tillage.

Should farmers adopting land-using technologies in the baseline situation prevail, there would be greater likelihood that the erosion problem would become more serious than at present. Our projection of land harvested with land-using technologies in the baseline situation is

9 million hectares more than were harvested in any year in the period 1910-1976,[12] and 23.1 million more than were harvested in 1975/76. The projection with land-using technologies in the high-demand situation implies even heavier pressure on the nation's supply of present and potential cropland.

The study by the Soil Conservation Service of potential cropland showed that in 1975 there were about 45 million hectares of land with high or moderate potential for conversion to cropland. If all of this land were converted, the total amount of cropland would be 207 million hectares,[13] just about enough to accommodate the 182.3 million harvested hectares projected in the high-demand situation with land-using technologies plus an additional 24 to 30 million hectares needed for fallow, cropland pasture, crop failure, and a small amount of inevitably idle land. However, just under 60 percent of the high-to-medium potential land is exposed to some kind of erosion problem. On more than one-third of these exposed hectares, costs of erosion control and water disposal systems would be high or very careful management would be required because of high wind or water erosion hazards.[14]

Almost half (21.9 million hectares) of the high and medium potential land is in the Corn Belt, the Plains states, and the Mississippi delta.[15]

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[12] U.S. Department of Agriculture, Changes in Farm Production, p. 16. The data for harvested land in this source begin with 1910.

[13] Soil Conservation Service, "Potential Cropland Study."

[14] Ibid.

[15] Ibid.

These are areas already heavily specialized in the production of grains and soybeans, and it is likely that much of any increase in cropland in the United States will occur in these areas. Ten million hectares of the 22 million of high and medium potential in these areas are especially exposed to the risk of erosion.[16] In fact, the hilly loess soils along the Mississippi and Missouri rivers are among the most erosive in America.[17] With respect to the western Corn Belt, it is asserted that "Soil erosion is the dominant limitation to agriculture on at least 30 percent of the region's cropland, and this cropland's potential contribution to watershed sediment yield is very high."[18]

The large amount of land that would be converted to crops in all projected situations but the baseline with land-conserving technologies and the fact that the erosion risk on much of this land likely is high suggest that the erosion problem in the United States could become much more serious by 1985 than it was in the mid-1970s. Whether this happens will depend in good measure on the rate of spread of minimum, or conservation, tillage

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[16] Ibid.

[17] Davis, "Soil Conservation." Davis is the Administrator of the U.S. Soil Conservation Service. Loess soils are those deposited by wind. They are generally fine textured and loosely aggregated compared to other types of soil.

[18] Amemiya, "Conservation Tillage." The western Corn Belt consists of the states of Iowa and Minnesota, all but the extreme south of Missouri and roughly the eastern quarter of Nebraska, South Dakota and North Dakota.

relative to conventional tillage.[19] To our knowledge, the economics of conservation tillage has not been comprehensively studied, but there clearly are many circumstances when it is competitive with conventional tillage. As noted earlier, conservation tillage spread rapidly in the 1960s, and by 1976 almost 16 million hectares of cropland, 11 percent of the total harvested, were treated with some form of conservation tillage.[20] Experience from around the country suggests that in a wide variety of circumstances yields of grains and soybeans are about the same or a little less with conservation tillage than with conventional tillage, but that cost savings with conservation tillage more than offset any sacrifice of yields. Typically labor and machinery operating costs are less with conservation tillage and pesticide costs, particularly for herbicides, are higher. Also in a small grain-soybean rotation conservation tillage, by eliminating mold board plowing, can significantly reduce the time between grain harvest and bean planting.[21]

Because of its economic advantages under a wide variety of circumstances it is highly likely that conservation tillage will continue to displace conventional tillage in the United States. The USDA has estimated that by

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[19]The principal difference between conservation and conventional tillage is that conservation tillage leaves residues from previous crops on the land and also a rougher soil surface. (Amemiya, "Conservation Tillage.") Conservation tillage includes a wide variety of practices from no tillage in which seed is planted directly in the residue from the previous crop in cuts only two inches wide or less (Griffith, Mannering, and Moldenhauer, "Conservation Tillage") to techniques which include harrowing and disking, but not mold board plowing.

[20]Davis, "Soil Conservation."

[21]See the Journal of Soil and Water Conservation vol. 32, no. 1, January-February 1977, especially articles by Bennett ("Conservation Tillage"), Reicosky, Cassel, Blevins, Gill, and Naderman ("Conservation Tillage"), and Griffith et al. ("Conservation Tillage"). On the economics of conservation tillage, see also Office of Planning and Evaluation, Minimum Tillage.

2000 as much as 111.5 million hectares of cropland could be under some form of conservation tillage.[22] Expansion of the technique on this scale would imply a large increase in conservation tilled land by 1985, although no precise estimate is at hand.

The USDA estimates that if land under conservation tillage reaches 111.5 million hectares by 2000 total soil loss to erosion from cropland would be 50 percent less than it would be with no increase in conservation tillage.[23] Without necessarily endorsing this estimate, we believe there is no doubt that wide adoption of conservation tillage would greatly reduce total erosion. The evidence is very strong that with conservation tillage soil lost to erosion is reduced 50 to 90 percent compared with conventional tillage, depending upon type of soil, slope of the land, crop rotation, and other factors.[24]

The future importance of the erosion problem also will be influenced by farmers' incentives to adopt erosion control practices, such as terracing, contour plowing, strip cropping, provision of grass waterways to handle runoff, planting of trees for wind breaks, and so on. The effectiveness of these practices in reducing erosion varies widely according to soil characteristics, slope of the land, crop rotation, amount and intensity of rainfall, and other factors. For example, a study by Swanson and Maccallum showed that soil loss on a particular soil type in Illinois was 72.7

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[22] Office of Planning and Evaluation, Minimum Tillage.

[23] Ibid.

[24] See the articles by Griffith et al., Reicosky et al, and others in the Journal of Soil and Water Conservation vol. 32, no. 1, January-February 1977.

metric tons per hectare when planted to continuous corn cultivated up and down the slope, the slope was 6 percent and the slope length was 45 meters. If contour plowing was substituted for up-and-down plowing, soil loss was reduced by half. If a corn-corn-soybean-oats rotation was substituted for continuous corn, the slope was 2 percent instead of 6 percent and the slope length 75 meters instead of 45 meters, soil loss with up-and-down plowing was 20.7 metric tons per hectare instead of 72.2 metric tons. Substituting contour plowing for up-and-down plowing reduced soil loss by 39 percent. Under the same sets of conditions soil losses on two other soil types considered were substantially less than on the first type, and substitution of contouring for up-and-down plowing had effects in reducing soil loss comparable to those just noted.[25]

Farmers' incentives to adopt these erosion control practices depend not only on their effectiveness in reducing soil loss but on a host of other technical and economic conditions. For example, the principal gain to the farmer of reducing erosion is the maintenance of the productivity of his soil. If his topsoil is deep, or if it is shallow but the underlying soil material is favorable, he will suffer less loss of productivity for a given amount of erosion, hence have less incentive to control erosion, than if these soil conditions are reversed. The rate of interest also enters the calculations because the costs and benefits of erosion control practices occur over a number, perhaps many, years, hence must be converted to present values by discounting. The effect of variations in the interest rate on incentives to adopt erosion control practices will depend upon the distribution over time of costs relative to benefits. In general, the longer benefits

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[25]Swanson and Maccallum, "Income Effects."

are deferred relative to costs the more unfavorable the impact of high interest rates on incentives to control erosion.

The cost of fertilizer also will influence the farmer's decision about erosion control since, within limits, heavier applications of fertilizer can offset loss of topsoil. Hence the higher the price of fertilizer, the greater the incentive to adopt erosion control practices. Crop prices also are important, the higher they are the weaker the incentive to keep any land out of crop production, for example, by putting some in trees or windbreaks or by strip cropping. The kind of machinery may be a factor. There is evidence that a growing number of farmers are finding terracing uneconomic because the increasing size of farm machinery makes it difficult to maneuver on terraces.

The net effect of the numerous factors affecting farmers' incentives to adopt erosion control practices of course will vary from place to place and from time to time. Swanson and Maccallum found that with the price, yield, soil, and other relevant conditions prevailing in Illinois in the late 1960s contour plowing gave higher returns than plowing up-and-down the slope. The reason was that contouring reduced soil losses so much relative to up-and-down plowing that the resulting gains in soil productivity more than offset the additional cost of contouring.[26] The analysis of Swanson and Maccallum thus provides evidence that economic and technical factors may in some circumstances provide incentives to adopt erosion control practices. There surely are other circumstances, however, in which they would not. In any event, it can be assumed that farmers generally will not adopt erosion control practices unless the practices are perceived

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[26] Ibid.

to be economically advantageous to the farmer. The social advantages from reduced off-farm erosion damages will not weigh heavily in the farmers' calculations, if at all. Hence, whatever erosion control practices farmers may adopt in response to private incentives, they likely will fall short of those needed to fully serve the social welfare.[27]

The discussion indicates that if the amount of cropland harvested approaches the higher end of the range projected in table 21 the erosion threat would tend to increase because much of the additional land would be of a sort particularly likely to erode. Offsetting this, however, is the expected continued spread of conservation tillage. Whether technical and economic conditions would provide farmers incentives to adopt erosion control practices on a significant scale cannot now be foreseen, but in any case adoption would be guided by calculations of private gain, not the social welfare. What the balance of these several factors might be with respect to the future severity of the erosion problem cannot now be foreseen. However, we think the threat of increased erosion is serious enough to justify reconsideration of present erosion control policies. We return to this below in the section on policy.

Environmental Impacts of Resource Use: Fertilizers

The Present Situation

Fertilizer consumption in the United States more than tripled between 1950-54 and 1971-75, rising from an annual average of 5.0 million metric tons

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[27] Swanson and Maccallum ("Income Effects") show that while under the conditions studied farmers would have incentives to adopt contour plowing instead of up-and-down plowing and this would significantly reduce erosion, the remaining amount of erosion would still be more than that believed "tolerable" by the Soil Conservation Service.

of nutrients to 16.3 million metric tons. Nitrogen nutrients increased more than fivefold from 1.45 million tons to 7.71 million. Concern about the environmental impacts of fertilizers in the United States mounted rapidly from the mid-1960s, part of the increasing general anxiety about the environment and the effects of man's activities upon it. In the case of fertilizer, attention focused on various effects of nitrogen on human and animal health and on the effects of nitrogen and phosphorus in speeding eutrophication of water bodies by stimulating growth of aquatic plants. Nitrates in water may constitute a hazard to both humans and animals that drink the water, not because nitrates themselves are particularly toxic but because of their potential for conversion to nitrites which are toxic, or can be when in sufficient concentration. Babies are more likely to suffer from nitrite poisoning than adults. Deaths and illnesses among farm animals also have been attributed to nitrite intoxication.[28] Nitrogen gas dissolved in water or nitrogen in ammonia may kill or injure fish.[29] There also is evidence that a portion of nitrous oxides released by denitrification of nitrogen fertilizers is subsequently converted to nitric oxide and nitrogen dioxide which attack the earth's ozone shield, thus permitting increased solar radiation to reach the earth's surface and exposing more people to the risk of skin cancer.

The evidence about the present seriousness of the environmental hazards of fertilizers is not easy to interpret. Numerous studies show the presence of nitrates in groundwater, for example, in parts of Connecticut, Long Island, Illinois, the High Plains, Minnesota, and California.[30] In some of these places the nitrate level has exceeded ten parts per million, the

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[28] Luhrs, "Human Health."

[29] Patrick, "Aquatic Systems."

[30] Martin, Fenster, and Hanson, "Fertilizer Management," and Miller, DeLuca, and Tessier, Groundwater Contamination.

standard for drinking water set by the Public Health Service. It is not clear, however, that fertilizer used in agriculture is the principal source of the nitrate in these waters. Martin and coauthors[31] cite a study by Smith of 6,000 rural water supplies in Missouri which concluded that animal wastes and septic tank drainage were the principal sources of nitrates. Studies in Minnesota show that rural wells were contaminated by nitrate long before fertilizer use became important, and that between 1899 and 1963 change in the quality of water in major aquifers was minor A study of an area near San Luis Obispo, California, showed that nitrate in groundwater "...was substantial and mostly associated with the native soil organic matter complex supplemented with sewage waste from area homes and to a lesser extent from lawn and farm fertilization."[32] In their study of groundwater pollution in the northeastern states Miller and coauthors[33] assigned a "moderate" priority to fertilizer for additional research and control measures while giving high priority to domestic, municipal, and most other sources of wastes.

The extent of fertilizer pollution of surface waters in the United States also is unclear, although the problem seems to have been less investigated. In a study of the southern High Plains Goldberg concluded that "nitrogen ferilizer applied to the farmland adds little nitrate to the surface water."[34] Aldrich says that the nitrate content of rivers in the central Corn Belt for which long-term records are available shows an upward trend. The nitrate content of the Mississippi River at the point

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[31]"Fertilizer Management."

[32]Ibid., p. 151.

[33]"Groundwater Contamination," p. 309.

[34]Goldberg, "Sources of Nitrogen." This conclusion cannot be applied to the United States as a whole because there is relatively little runoff to surface waters in the southern high plains.

where it leaves the Corn Belt about doubled from the mid-1950s to the mid-1970s but was still less than the maximum acceptable amount set by the U.S. Public Health Service for drinking water. The nitrate content of the Illinois River increased about one-quarter in this period but still was only about one-half of the Public Health Service's standard, while the nitrate in the Missouri declined about 50 percent between 1950 and 1970. In some small creeks and rivers in Illinois, however, the nitrate content exceeds the standard.[35]

The National Academy of Sciences cites a report on fertilizer pollution in Illinois by the Illinois Pollution Control Board (IPCB) which concluded that "there is no factual basis for imposing restrictions on the use of fertilizer at this time."[36] The conclusion applied both to nitrogen and phosphate fertilizers. With respect to phosphates, particularly suspect in speeding eutrophication of water bodies, the IPCB determined that about 25 percent of the phosphate in streams and lakes was attributable to agriculture, the rest coming from detergents and sewage. However, "there was insufficient evidence that fertilizer applied to soil in Illinois contributed significant phosphorus to those waters where the problem is serious."[37] The EPA subsequently issued a policy statement in general agreement with the decision of the IPCB regarding fertilizer, but it also stressed the need for additional information.[38]

The threat of nitrogen fertilizer to the ozone shield is particularly hard to evaluate because the evidence still is quite limited. The potential

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[35]Aldrich, "Perspectives on Nitrogen."

[36]National Academy of Sciences, Agricultural Production Efficiency, p. 92.

[37]Ibid.

[38]Ibid., p. 93.

for damage may be serious, however. McElroy estimates that within forty years the effects of nitrogen fertilizer may reduce the ozone shield by at least 10 percent.[39] The result likely would be some tens of thousands of cases of skin cancer in addition to those that would occur from other causes.

In our reading of the evidence on the environmental threats of fertilizer, two important aspects stand out. One is that human deaths or illnesses attributable to nitrite poisoning are extremely rare. Animal poisonings are more common, but where caused by drinking water the nitrate content of the water was seven to fifteen times the standard set by the U.S. Public Health Service.[40] Enforcement of the standard should eliminate such instances. Fish kills or injuries attributable to forms of nitrogen in surface water also are of small overall importance.

The second aspect is that much of the nitrogen and phosphorus found in water bodies comes from municipal and industrial discharges and from the natural leaching of these nutrients already in the soil.

Consideration of these two aspects of the evidence leads us to conclude that with present levels of use fertilizers do not pose threats to the environment so severe that changes in present policies are required to deal with them.

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[39] Michael McElroy of Harvard University has pioneered the research showing that nitrogen fertilizers threaten the ozone shield. Aldrich ("Perspectives on Nitrogen") makes an argument which is critical to thinking about policy to deal with the threat of nitrogen to the ozone shield. He asserts that if McElroy is right, the threat would occur also if substitutes for nitrogen fertilizers were developed, such as improved capacity of bacteria to fix nitrogen in legumes or development of this capacity in non-legumes. According to Aldrich's argument, the threat comes from nitrogen released to the atmosphere in the process of plant growth, whatever the source of the nitrogen. There is more in this below in the section on policy.

[40] Aldrich, "Perspectives on Nitrogen."

The Future Situation

Our projections of fertilizer consumption in the United States are reproduced for convenience in table 23.

Table 23

Fertilizer Consumption in the United States

(million metric tons)

	1985			
	Baseline situation		High-demand situation	
1976	LCT	LUT	LCT	LUT
18.3	22.7	22.6	26.3	25.9

Source: Table 17. LCT means land-serving technologies, and LUT means land-using technologies.

We concluded in the previous section that the levels of fertilizer consumption prevailing in the mid-1970s in the United States did not constitute a major environmental threat. Whether the level of consumption projected for 1985 would change that conclusion by then is uncertain. There is no known threshold of total or per hectare fertilizer use beyond which environmental damage becomes serious. For what it's worth the projected total fertilizer consumption in the high-demand situation would be about the same amount as was consumed in Europe (excluding the USSR) in 1970. Per hectare consumption in the United States in the high-demand situation with land-conserving technologies (163 kilos) would be about 15 percent less than in Europe in 1970.[41]

[41] University of California, A Hungry World, p. 99. In 1970 fertilizer consumption per hectare of arable land in Europe was 171.5 kilos. (Ibid.) Harvested land would be less than arable land, although we have no data indicating how much less. If it were 10 percent less, then fertilizer consumption per hectare of harvested land in Europe in 1970 would have been 191 kilos compared to the 163 kilos per hectare projected for the United States in the high-demand situation with land-conserving technologies. In the United States in 1970 harvested land was less than 65 percent of arable land.

Studies of fertilizer pollution in Europe suggest that pollution of surface and groundwaters was not a major problem in that area at 1970 levels of consumption. A study of eutrophication in Switzerland asserted that there was some concern about this problem with respect to lakes, but not rivers. Phosphorus was determined to be the major factor in speeding eutrophication of lakes, but 50 to 75 percent of the phosphorus was carried by municipal waste waters, the remaining 25 to 50 percent being leached or eroded (primarily the latter) from cultivated and uncultivated soils.[42] In Bulgaria fertilizer consumption per hectare was 180-200 kilos around 1970, 20 to 25 percent more than our projection with land-conserving technologies. A study of four districts covering the period 1953-1966 showed a correlation between the amount of fertilizers applied and the percentage of water containing nitrates. However, at the end of the period the amount of nitrate in the water was "low."[43] A study of seventeen rivers in England during 1953-1967 showed the nitrate concentrations did not increase significantly despite a substantial increase in fertilizer consumption in the areas drained by the rivers. The author of the study suggested that the lack of correlation was because most of the nitrate leached from the soil comes from the large reserves of soil nitrogen and not directly from added fertilizers.[44] Based on this and similar studies in other European countries, Holliday concluded that ". . .the contribution of nutrients from fertilizers applied to agricultural land to inland waters and rivers is generally small in relatively heavily populated developed countries in relation

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[42] Jaag, "The Main Sources."

[43] Garbouchev and Mitneva, "Research on the Effects of Intensive Fertilizer Use."

[44] Holliday, "Eutrophication of Inland Waters."

to the contribution from sewage effluents from urban areas." With particular reference to eutrophication he asserts that "...the increase in the nutrient content of waters which results from the use of fertilizers on agricultural land is rarely a critical factor in eutrophication, in the narrower sense of "blooms" or algae, except occasionally in hard rock and highland areas.[45]

The discussion of European experience with fertilizer pollution of water suggests that the problem may not become serious in the United States in 1985 even if total consumption that year is at the maximum projected level of 26.3 million metric tons. This conclusion obviously depends on the assumption that fertilizer consumption per hectare of cropland is a proper measure of the threat to water quality from fertilizer, and that European experience is relevant to the United States. The per hectare measure may be misleading if land-water (including groundwater) relations are different between Europe and the United States. For example, phosphates enter water bodies primarily by adhering to soil particles from eroded land. If the rate of erosion of soils to which phosphate fertilizer has been applied is different in the United States than in Europe, the simple comparison of per hectare amounts of fertilizer will be misleading so far as the eutrophication problem is concerned.

The threat to the ozone shield from nitrogen fertilizer, if there is one, results from consumption worldwide, not just in the United States. Moreover, the threat may not be exclusively from fertilizer but from all fixed nitrogen not taken up by plants. Some of the implications for policy of these facts are discussed below.

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[45] Ibid., page 295.

Environmental Impacts of Resource Use: Pesticides

The Present Situation

The severity of the hazards from present levels of pesticide use in the United States is hard to determine, in large part because we know too little about how pesticides move through the environment and the damages they do to unintended targets. Consequently, judgments about the environmental impacts of these materials, when they can be made at all, must be highly tentative. Our discussion of them deals with insecticides and herbicides.[46]

Insecticides As noted in the previous chapter, the EPA has suspended use of some of the organochlorine insecticides, namely DDT, aldrin, dieldrin, chlordane, and heptachlor. This action was taken in large measure because of evidence from experimental animals that these materials may cause cancer in humans. While this action will prevent further introduction of these materials into the environment, residues from past use will be present for some years because these materials resist degradation. If they do cause cancer, many cases will not show up for twenty or thirty years because of the long latent period of the disease.

It was pointed out in the last chapter that use of the organochlorine compounds as a group declined from 1966 to 1971 but that the decline was more than offset by increased use of organophosphorous and carbamate compounds. Many of these compounds are acutely toxic to humans and other non-target species, as well as to the insects for which they are intended. There are no good estimates of the number of persons poisoned

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[46]Insecticides and herbicides account for 80 percent of all pesticides used on American farms in 1971. Fungicides, 8 percent of pesticide use, are only slightly toxic or are non-toxic to mammals (Environmental Protection Agency, Production, Distribution, Use). Consequently, in concentrating on insecticides and herbicides we miss little of significance concerning environmental impact.

by these insecticides. California is the only state with a systematic procedure for reporting events of this sort. Even there the data base is too weak to permit accurate estimates of non-fatal poisonings from insecticides, although there is evidence that the number of cases is far larger than that reported. Fatalities in California, for which better estimates are available than for non-fatal poisonings, seem relatively low. In the period 1951-1970 there were 23 occupational and about 100 nonoccupational deaths due to pesticides. The latter include suicides, homicides, and children who unknowingly drank or were otherwise exposed to pesticides.

There are no entirely reliable data showing deaths by pesticides in the nation as a whole. Such studies as have been done indicate that most fatalities, as in California, are nonoccupational. One such study indicated that nationwide about twelve people died of occupational pesticide poisoning in 1969. There are no data for the nation as a whole showing non-fatal poisonings.

Many people expected that the substitution of organophosphorous and carbamate compounds for chlorinated hydrocarbons would result in an increase in pesticide fatalities. Although national data are not available, spot checks of state data give no evidence that this occurred.[47] Even if true, these data say nothing about non-fatal poisonings, however. We believe it likely that the number of these has increased with the switch from chlorinated hydrocarbons to organophosphorous and carbamate compounds.

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[47] All of these data on pesticide poisonings are from National Academy of Sciences, Pest Control vol. 1, pp. 87-90.

From the standpoint of environmental impacts, the organophosphorus and carbamates do have a significant advantage over the chlorinated hydrocarbons in at least one respect. With few exceptions they are quickly degraded after release in the environment and do not accumulate in the food chain. Both field experience and experimental work demonstrate this for the most important of these materials, malathion, parathion and methyl parathion, carbaryl, and carbofuron.[48] Persistence and bio-accumulation, characteristics of the important chlorinated hydrocarbons, are known to have adverse impacts on birds, fish, and perhaps humans. Consequently, the fact that the organophosphorous and carbamate compounds do not have these characteristics is a plus for the environment. This does not mean, however, that the organophosphorous and carbamate compounds are innocent of long-term adverse effects on the environment. This issue has been little studied, so the lack of evidence in this regard proves nothing. If there are long-term impacts of these compounds, however, they would be associated with characteristics other than persistence and bio-accumulation.

There is another, perhaps more subtle respect in which the switch to organophosphorous and carbamate compounds may be favorable to the environment. Injury to humans and other non-target species by these materials result from their acute toxicity, meaning that the injury is severe and quickly evident. Consequently, both the victims and those responsible can usually be readily identified. The damages caused by the organochlorine compounds by contrast do not produce sudden, severe symptons but rather show up as impaired reproductive processes, cancer, or other long-delayed effects. In addition, because of the persistence and bio-accumulation properties of the organochlorines, it may be difficult if not impossible to determine the original source of

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[48] Metcalf and Sanborn, Pesticides and Environmental Quality.

the damaging materials and those responsible for them. Because of these differences in the timing and nature of the damages done, the organophosphorous and carbamate compounds likely would be easier to manage than the chlorinated hydrocarbons. The point is not that the potential environmental damages of the organophosphorous and carbamate compounds are less--they may in fact be more--but possibilities for managing these materials to avoid or reduce the damage may be greater.

Herbicides. There seems to be a consensus that the environmental impacts of herbicides are much less serious than those of insecticides. A report of a commission of the Secretary of Health, Education and Welfare, published in 1969, asserted that "Herbicides, as presently used, do not present serious widespread hazards to nontarget organisms. With few exceptions, most herbicides have a low order of toxicity to aquatic and terrestrial animals."[49] This apparently still is the prevailing view, although a more recent report says that herbicides are relatively nontoxic to mammals (not all animals) and that by virtue of their physical, chemical and biological properties they are more likely to affect the lower than the higher trophic levels of food chains. The latter characteristic is significant because little is known about these lower level effects under field conditions, and it is not clear that currently used monitoring techniques are sufficiently sensitive to detect such effects before the occurrence of massive ecological damage.[50]

As noted at the outset of this assessment the paucity of information about the environmental impacts of pesticides makes judgments about these impacts difficult at best if not impossible. We risk such a judgment

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[49]U.S. Department of Health, Education and Welfare, Report of the Secretary's Commission, p. 203.

[50]Environmental Protection Agency, Production, Distribution, Use, pp. 96 and 103.

nevertheless, concluding that the weight of the evidence indicates that the present severity of the pesticide problem is not such as to require major new policies to deal with it. We re-emphasize, however, that the evidence necessary for such a judgment, especially that concerning long-term effects and those at lower trophic levels of the food chain, is quite fragmentary. Consequently, the judgment is tentative, subject to change as new evidence becomes available.

The Future Situation

Our projections of pesticide consumption in the United States are reproduced for convenience in table 24.

Table 24

Pesticide Consumption on Crops in the United States

(million kilos, active ingredients)

		1985			
		Baseline production		High production	
	1971	LCT	LUT	LCT	LUT
Insecticides	70.1	77.5	82.2	90.3	94.8
Herbicides	102.6	230.9	200.5	267.8	229.7
Fungicides	18.0	21.4	23.4	24.2	27.3
Miscellaneous pesticides	21.0	23.1	22.5	27.4	25.5
Totals	211.7	352.9	328.6	409.7	377.3

Sources: Tables 19 and 20. LCT means land-conserving technologies and LUT means land-using technologies.

One's judgment about the future severity of the pesticide problem in the United States, given these projections, will be much influenced by the weight one gives the arguments that organophosphorous and carbamate compounds are less damaging to the environment than the organochlorines and that herbicides are relatively innocuous. If one accepts these arguments, then one could conclude that despite the considerable projected increases in total pesticide consumption, there likely could be little if any additional damage to the environment.[51] If one is not convinced by the arguments, however, then the projected levels of use should be cause for concern, particularly those associated with the high production situation.

We believe the arguments have weight. However, the lack of knowledge about possible long-term effects of organophosphorous and carbamate compounds and about possible effects of herbicides on lower trophic levels of the food chain leaves us reluctant to accept the conclusions to which the arguments point. In the absence of that knowledge, we believe the prudent course is to assume that the projected levels of pesticide use may imply serious environmental problems, even though present levels of use may not.

Environmental Impacts of Resource Use: Salinity from Irrigation

The Present Situation

Salinity is the principal environmental problem peculiarly associated with with irrigation in the United States.[52] Irrigation water almost always

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[51] We have not projected the various types of insecticides separately, but we expect use of organochlorines to decline from the 1971 level, continuing the trend evident from 1966 to 1971. Therefore, all of the projected increase in insecticides, and more, is in organophosphorous and carbamate compounds.

[52] Irrigation practices contribute to several environmental problems. For example, the tail waters common to flood and furrow irrigation carry nitrates, phosphates, and pesticides while leaching carries nitrates into water bodies. While some irrigation practices may accelerate the passage of these chemicals into the common water bodies, these problems are similar to those discussed in previous sections.

contains dissolved salts which accumulate either in the soil or in the water left after evapotranspiration. Salt accumulation in the soil limits the plant's ability to take up water, impairing crop growth. As long as drainage is adequate, salt accumulations can be controlled by more liberal water applications which flush the salts beyond the root zone. This process, however, does not eliminate the environmental problem. It merely passes the problem on in the form of higher salt concentrations to the next user of the drainage waters. In addition to lower yields and higher water use for leaching, salinity increases management and operating costs and accelerates the corrosion of pipe and other equipment. In a few areas the accumulation of dissolved salts has left soils or surface and groundwater supplies virtually worthless for agricultural uses. Less severe but significant problems are much more widespread in the West.

One of the difficulties in assessing and dealing with the salinity problem is that irrigation is only one of the sources. Salinity resulting from natural processes often may be more important than salinity from irrigation, and the relative importance of different sources varies widely from place to place.

Evans cites estimates of the U.S. Regional Salinity Laboratory indicating that 28 percent, or about 4 million hectares of the irrigated land in the seventeen western states is "adversely affected" by salinity.[53] The Columbia River is the only major river system in the West that is not confronted with high and generally rising salt levels in important reaches of the river.

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[53] Evans, "Finding Knowledge Gaps," p. 154.

Estimates of the losses in terms of crop yields are not available. The nature of the problems, however, can be illustrated with a brief review of the situation in the Colorado River Basin. Although the salinity problems in this basin are the nation's worst, the situation in the Colorado Basin can be viewed as a precursor of the problems that might be expected from a continuation of current management practices and water use trends in other regions.[54]

The headwaters of the Colorado River are generally of excellent quality. Yet, the salt concentrations of waters delivered to the lower basin are approaching the maximum acceptable levels for some users. An average of over 26,000 tons per day of dissolved solids are delivered to the surface waters of the upper Colorado Basin, 61 percent of which comes from natural sources such as saline springs and surface runoff. Irrigation contributes over 9,600 tons of salts per day on the average, which is about 96 percent of the total attributable to man's activities. In the lower basin, the water of the Colorado continues to become increasingly saline as one moves downstream. Based on the 1941 to 1966 average observed by monitoring stations along the river, the total dissolved solids in milligrams per liter (mg/l) were 586 at Lees Ferry in northern Arizona, 647 near the Grand Canyon, 734 below Hoover Dam, and 849 at Imperial Dam. Much higher average salinity levels are encounted in some areas of the basin. For example, the discharges from the Welton-Mohawk Main Outlet Drain average 4,400 mg/l.

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[54] A description of the impacts of irrigated agriculture on the water quality of various river basins is available in National Commission on Water Quality, Cost and Effectiveness of Point Source Pollution Control, chapter 2. This source and U.S. Department of Interior, Westwide Study, pp. 175-181 provide the basis of the following discussion on the Colorado River Basin.

The damages attributable to salinity in the Colorado River system in 1973 were estimated at $53 million, excluding any damages for municipal and industrial supplies below 500 mg/l and agricultural damages below 750 mg/l.

Most studies of the damages resulting from use of saline waters in irrigation take farm management practices regarding water use and cropping patterns as given. Yet, there is now evidence that farmers will shift these practices to reduce damages rather than accept yield losses or lower acreage.[55] For example, in southern California and Arizona some farmers are using custom sprinkling with saline water during the germination and seed emergence stages, after which furrow or flood irrigation is used. These methods have enabled farmers to maintain yields with water that is conventionally regarded as excessively saline for such crops. Whether these practices will enable farmers to maintain yields over the long run is an open question. At a minimum, however, it seems likely that progressively heavier applications of such water may be required to prevent salt build-up in the soil.

The various studies reviewed by us indicate that the nature and importance of the salinity problem associated with irrigation in the western United States are not well understood. There seems to be a consensus that while the problem is getting worse, improved water management techniques and agricultural technology can halt and perhaps reverse this trend. Considerably more work must be done in agronomy, soil science, genetics, and related disciplines to obtain a clear assessment of the nature and importance of the salinity problem and to develop improved technologies for countering the problem in irrigated agriculture.

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[55] Bresler and Yaron, "Soil Water Regime"; Kleinman, Barney, and Titmus, Economic Impacts; Moore and Sayder, Management of Saline Water.

While agriculture is the primary sector affected by the high salinity levels, the costs per unit of water may be considerably higher for some other users. High salt levels create treatment problems and costs for municipal and industrial water users. For example, a study by the Orange County Water District in southern California, which receives part of its water from the Colorado River, estimates the quality-related costs incurred by a single-family household receiving Colorado River water at $227 per acre foot higher than for a similar household receiving high-quality water with only 200 milligrams of total dissolved solids per liter.[56]

The Future Situation

We have not made projections of water used in irrigation or of irrigated acreage. As indicated in the previous chapter, however, we believe that water in the seventeen western states will become more expensive because of rising energy costs, declining water tables, and increasing demand for water for nonagricultural uses. Consequently, we believe that even in the high-demand situation the expansion of irrigated acreage in those states from 1975 to 1985 will be slight by comparison with the previous decade.

Nevertheless, in the absence of effective control measures, the salinity problem in the region will continue to worsen as salts continue to accumulate in many soils, aquifers, and rivers. And rising nonagricultural water demands will impose greater constraints on the quality and quantity of water available for farmers to effectively counter high salinity levels.

Bureau of Reclamation estimates suggest that by the end of the century the levels of dissolved salts in the Colorado will average generally

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[56]Wesner, "The Importance of Salinity in Urban Water Management," p. 113.

25 to 35 percent above recent levels unless effective control measures are implemented. For example, the average concentrations of dissolved solids in 2000 are projected at 770 mg/l at Lees Ferry, 930 mg/l below Hoover Dam and 1,160 mg/l at Imperial Dam. The annual basin-wide damages from these salinity levels are estimated at $124 million with no allowance for the impacts of increasing salinity on fish and wildlife and other environmental resources.[57]

At least some control measures in the Colorado Basin must be adopted to comply with international obligations regarding the quality of water delivered to Mexico. The United States already has incurred considerable expense to reduce salinity from the high levels of the early 1960s which threatened the viability of Mexican agriculture in the valley. However, additional measures are required to satisfy future obligations. The United States has authorized construction of a 100 million gallon-per-day desalting plant to clean up the water delivered to Mexico even though the costs of constructing and operating the plant would far exceed the benefits of improving the water quality for agricultural uses. Comparable amounts of salts could be removed from the Colorado at much lower cost by controlling the irrigation return flows in some of the areas that contribute large quantities of salts to the flow. Thus, construction of the proposed desalting plant would represent a failure to adopt a more comprehensive plan to regulate the use of the river for the overall benefit of U.S. and Mexican users.

There appears to be substantial room for reducing agricultural water use without reducing the overall value of agricultural production throughout the western states. Not only is water use generally well in excess of the

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[57] U.S. Department of Interior, Westwide Study, pp. 176-177.

needs of the crops planted but much of the irrigated land is planted to crops with low returns to water. The increasing scarcity and rising costs of water are likely to force many farmers to reduce the quantities of water applied to particular crops even though this may increase salinity damages. The extent of the damages would depend in large part on the development and adoption of on-farm technologies for cultivating salt-laden soils and irrigating with saline water.

The present allocation of large quantities of irrigation water to alfalfa, a relatively low value crop, also suggests considerable potential for dealing with the future salinity problem while maintaining the value of agricultural production without increasing and perhaps even reducing total water use. In 1969 there were about 2 million irrigated hectares of alfalfa, equivalent to nearly 15 percent of the total irrigated land in the seventeen western states. Alfalfa is one of the most water consumptive of all crops. For example, relative to alfalfa, the approximate evapotranspiration rates are 25-30 percent for small grains, 30-45 percent for corn and sorghum, 25-40 percent for potatoes, and 15-30 percent for vegetables.[58] Undoubtedly, there are problems associated with the adaptability of alternative crops to the soils and climates of some of the irrigated alfalfa areas, and alfalfa is more tolerant of salinity than some crops such as corn. Nevertheless, the fact that more irrigated land in the West is devoted to alfalfa than any other single crop also reflects the unrealistically low cost of water to farmers. As water costs and concerns with future supplies rise, these cropping patterns should shift toward higher valued crops. In

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[58] U.N. Food and Agriculture Organization, Crop Water Requirements, p. 60.

addition some of the water diverted from alfalfa could be used for controlling soil salinity on land in these crops. And if salinity levels become an important determinant of crop choice, there are other crops, notably barley, that have much higher salt tolerance levels than alfalfa.[59]

Policy Issues

Introduction

We believe a clearer case can be made for rethinking policies to control erosion than for policies to control pesticides, fertilizers, and salinity. There are three reasons. In the first place, the evidence of serious future damage to the environment is clearer, in our judgment, with respect to erosion than it is with respect to fertilizers and pesticides. While salinity damages are likely to rise, the scale of the problem, in our judgment, is less than in the case of erosion. With respect to fertilizers and pesticides we do not say that erosion will constitute a more serious environmental threat, only that the evidence concerning the threat is clearer. The evidence for fertilizers and pesticides, particularly the latter, is too fragmentary to draw firm conclusions about potential environmental damages. The lack of evidence impedes fruitful thinking about new policies.

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[59] U.N. Food and Agriculture Organization, Water Quality for Agriculture, pp. 26-32.

In the second place, control of erosion helps to reduce the environmental damages of fertilizers and, to a lesser extent, pesticides. Phosphorous fertilizers get into water bodies primarily by adhering to particles of eroded soil. Consequently, reducing erosion also reduces water pollution by these fertilizers. Nitrogen fertilizers are carried to surface waters by runoff and to groundwater by filtration. Reducing erosion often will reduce runoff, and hence help to control nitrogen pollution of surface waters. However, reduced runoff likely will mean increased filtration to groundwater. The net effect of greater erosion control on pollution of water by nitrogen thus is uncertain. There is a clear gain, however, in reduced pollution by phosphorous fertilizers.

Many pesticide residues adhere tightly to soil particles, and erosion is the major route by which these residues move from the farmers' fields to surface water bodies.[60] Consequently, controlling erosion will reduce pollution of water by pesticides. It is important to note, however, that the reduction will be greatest for persistent pesticides, mostly the organochlorines, since more volatile compounds will not last in the environment

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[60] Environmental Protection Agency, Methods and Practices.

long enough to be washed into water bodies. Since consumption of persistent pesticides already is less than half of total pesticide consumption, and s' ll dimi:.ishing in importance, control of erosion would deal only with a part of the problem of pollution from pesticides.

In the third place, current policies to control erosion are weaker, hence in greater need of repair, than those to control pesticide pollution. At present, erosion control policies are the responsibility primarily of the Soil Conservation Service, and they rely on providing farmers various economic incentives to adopt erosion control practices. Experience since 1973 indicates that when crop prices are high, the market provides many farmers counter incentives strong enough to override those provided by erosion control policies, leading these farmers to abandon or modify erosion control practices. If the high demand situation prevails, crop prices may well be high enough to greatly weaken, if not completely overwhelm, the erosion control policies we now rely on.

Regulation of pesticides is the responsibility of the Environmental Protection Agency (EPA), acting under the authority of the Federal Insecticide, Fungicide, and Rodenticide Act Amendments of 1972 (FIFRA). The EPA can order a ban on the use of any pesticide it judges to pose a serious threat to the environment, and if the ban is upheld in judicial proceedings, use of that pesticide ceases. As noted earlier, the EPA already has acted against DDT, aldrin, and dieldrin, and, at this writing, most uses of heptachlor and chlordane also have been suspended. Thus, for dealing with pesticides FIFRA provides the EPA with a demonstrably powerful policy instrument of a sort not presently available for control of erosion.[61]

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[61] This is not to say that the FIFRA instrument is always wielded in an optimum way. There is more on this below.

Erosion Policy Issues

While we believe priority should be given to new thinking about erosion control policies, we are not prepared to say what those policies should be. Instead, our focus is on the principal issues we believe should be discussed in the process of formulating a set of policies. We pose these issues in the form of questions.

1. What is an acceptable amount of erosion? The answer to this question will specify the objective of erosion control policy. There is no way to answer the question unless we have some measure of the damages likely to be done by erosion in the future. In the earlier discussion, we noted that at present there are no good estimates of present damages of erosion, either in loss of soil productivity or in downstream damages to reservoirs and so on. However, techniques for measuring both sorts of damages exist and there is no reason why acceptable estimates of damages could not be made. For example, studies of the sort already done of the relation between loss of topsoil and loss of productivity could be refined and applied on a wide scale to permit estimation of losses of productivity resulting from varying amounts of topsoil loss under a variety of conditions. Studies also have been done of the relation between sedimentation and loss of reservoir capacity. These could be undertaken on a scale sufficient to estimate these losses on a national scale, given varying amounts of gross erosion in the watershed upstream from each reservoir.

To be useful in formulating erosion control policies, the estimates of damages would have to be related to soil loss on each farm. Otherwise, it would be impossible to assign responsibility for the damages. Establishing this relationship for damages resulting from loss of productivity would be straightforward enough, but it would be very difficult in the case of downstream

damages. Application of the universal soil loss equation would give reasonably good estimates of the potential gross erosion from any farm, but the relationship between gross erosion and amounts of sediment delivered to some distant point downstream is extremely tenuous. The process of sediment delivery is highly complex and not well understood.[62] Lack of knowledge of this process could be a major bottleneck in implementation of erosion control policies.

2. How can farmers be induced to adopt practices which will hold erosion to a tolerable amount? As noted above, present policy relies upon providing economic incentives to farmers to adopt erosion control practices, and there is evidence that the policy does not work well where the market provides strong counter incentives. Making incentives to adopt control practices strong enough to override market incentives is possible but likely would be very expensive.

The EPA presumably has authority under section 208 of the Federal Water Pollution Control Act of 1972 to set limits on the amounts of soil that may be discharged to streams by any farm and to enforce these limits by the threat of both civil and criminal penalties. So far such limits have not been set, and the EPA is relying on so-called 208 planning undertaken by the states to determine what the limits should be and how they should be enforced. The planning still is in early stages in each state and the final shape of the plans and how they will propose to deal with the erosion problem cannot now be foreseen.

Given the large number of farms in the country and the great diversity of the soil, climatic, and other conditions relevant to erosion under which

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[62] Wolman, "Changing Needs." For a listing of the principal determinants of the sediment delivery ratio see pp. 87-88 in chapter 4 above.

they operate, the enforcement of erosion limits by legal means would seem to be a cumbersome and costly procedure. The regulatory agencies--the EPA or state and local bodies acting within guidelines established by the EPA--would have to have the capacity to monitor soil discharges over prolonged periods of time from each farm in the country to check compliance with the limits set for that farm. They also would have to be equipped to engage in legal proceedings in cases where farmers exceeded their limit and measures to secure their voluntary compliance failed. It is easy to believe that the number of these cases could be large, and the EPA already has many other things on its plate.

A regulatory system to induce, or to compel, farmers to abide by erosion standards obviously would require a large monitoring and enforcement effort. Such a system perhaps would be more effective in meeting erosion control objectives than the present system, but it likely would be much more expensive and surely more intrusive in farm management decisions. These additional costs of a regulatory system should be explicitly considered in thinking about the merits of such a system.

3. How can conversion of "fragile" (erosion-prone) lands to crops be contained? Our discussion of the demand for and supply of cropland indicated that under some conditions prospective demands could be met only by large-scale conversion to crops of land now in other uses, and that much of this land is especially prone to erosion. Restricting conversion of these lands within tight limits would prevent much erosion that otherwise would occur. Such a policy, however, would have to confront some serious issues. How might the policy be pursued? Farmers might be subsidized to withhold these lands from crop production, the technique used in the Soil Bank program adopted in the 1950s. However, if the incentives to bring additional land under crops are

as strong as some of our projections suggest, the amount of subsidy needed to offset these incentives likely would be extraordinarily high.

As an alternative, the federal, state, or local governments might buy these lands, using the principle of eminent domain, if necessary, to assure that they are not converted to crop production. This, too, would likely be a high cost policy, involving extended bargaining and litigation to establish fair rates of compensation and billions of dollars to buy the land even if the average purchase price were moderate. Perhaps a third alternative would be for local governments to apply the zoning principle to restrict fragile lands to noncrop uses. This would likely encounter stiff opposition from farmers, particularly if the demand for cropland approaches the high end of our projections. Moreover, zoning has been found vulnerable to pressure when economic incentives for changing zoning regulations are high.

A major question raised by erosion control policies, whether in the form of imposed soil loss limits or restrictions on conversion of fragile lands to crops, concerns the effect on the economic and environmental costs of crop production. The economic costs would surely be higher, at least in the short to medium run, than if soil loss limits were not imposed and the fragile lands were freely converted. The fact that these restrictions would have to be imposed on farmers is proof of this. How much higher the economic costs might be cannot be predicted without information about the future demand for crops and the cost of meeting that demand by increasing yields rather than bringing additional land under crops. If the potential of existing technologies for increased yields is about exhausted, as may be the case, the economic cost of meeting increased demand by land-conserving rather than land-using technologies may be high. The implications of this for the costs of food in

the United States should be carefully considered in thinking about a policy to restrict conversion of fragile lands as a measure to control erosion. Higher food costs not only directly reduce the real income of American consumers, with proportionally heavier impact on the poor, they also indirectly complicate the problem of controlling inflation and weaken the American position in world food markets, thus damaging our balance of payments.

Restrictions on allowable soil losses or on conversion of fragile lands to crops also may increase the environmental costs of fertilizers and pesticides, particularly if the marginal productivity of these key land-conserving inputs is low. In this case, meeting high demand for crops by increasing yields might require very large increases in the use per hectare of these materials. While improved erosion control likely would neutralize much of the potential for increased damage from higher fertilizer use, this would be less likely for pesticides, particularly if much of the increase is in consumption of the nonpersistent organophosphorous compounds.

Pesticide Policy Issues

Under FIFRA amendments of 1972, the EPA has strong authority to regulate the distribution and use of pesticides. The backbone of the regulatory process is the requirement that all pesticides be registered before they can be placed on the market.[63] In addition, the agency can prescribe and enforce the conditions of use of pesticides so as to reduce the risk of accident and injury in application or other inadvertent use.

The registration requirement gives the EPA legal authority to control the supply of pesticides. Since the number of pesticide manufacturers is relatively small, this control can be effectively implemented. This puts the

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[63] Environmental Protection Agency, Strategy, p. 9.

EPA in a much stronger position with respect to control of pesticides than the Soil Conservation Service, or the EPA itself, with respect to control of erosion.

In our judgment, a major issue with respect to pesticide control policies is lack of information necessary to wisely implement those policies. The EPA bases its actions with respect to pesticide registration and use primarily on information from laboratory and field tests on animals done by the manufacturer. These tests are inadequate to assure that unexpected adverse effects of pesticides will not occur when the materials are put to practical use. The EPA is fully aware of this limitation and is conducting and supporting scientific research to overcome it.[64] The nature of the problem is such, however, that answers may be long deferred. For example, an important gap in present knowledge concerns possible long-term effects on humans or other ecosystems of organophosphorous and carbamate compounds. As noted earlier in this chapter, there is little if any evidence suggesting there may be long-term effects, but the lack of evidence may reflect the absence of adequate tests of these materials.

A similar statement can be made about the current view that herbicides, in general, are nontoxic or only slightly toxic to animals. The tests of these materials may not have been sufficiently sensitive to pick up effects at lower trophic levels. The EPA is not doing or sponsoring much research designed to overcome this limitation. In view of the rapidly growing importance of herbicide consumption, the case for more research on these materials, in our judgment, ought to be reviewed.

The cost to private industry of developing new pesticides has risen since the mid-1960s, and increasingly stringent regulations by the federal

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[64] Ibid., pp. 14 and 16.

government are one of the major reasons why.[65] There is no evidence that this so far has reduced the number of new pesticides coming on the market annually, and, even if it had, this would not necessarily be a reason for relaxing the regulations since they presumably advance the public welfare.

Nonetheless, the impact of regulations on the cost of innovation is an important issue in thinking about pesticide control policies. Research to develop alternatives to existing pesticides is crucial to reducing environmental damages from pesticides over the long run. A main thrust of current research is to develop species-specific pesticides, such as chemicals which kill only a specific insect, juvenile hormones which disrupt the maturation process of a particular species, and pheromones which play on the sexual instincts of insects to destroy them. It is generally agreed that these techniques for pest control would be less harmful to the environment than those now employed. Because the new technqiues are species-specific, however, the potential market for any one of them is smaller than for the so-called "broad spectrum" pesticides now in common use. This would tend to make the unit costs of the new techniques higher than those of currently used pesticides. If government regulations increase these costs even more, incentives to develop these new techniques, or others like them, may be so weakened that work on them ceases.

As with respect to erosion, the effects of pesticide control policies on the economic and environmental costs of crop production are an important issue. These policies may lead to higher costs of new pesticides, as just noted, or may force farmers to adopt more expensive pesticides already on the market. They may also increase farmers' incentives to adopt more

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[65] National Academy of Sciences, Pest Control vol I., pp. 139-142.

land-using technologies. As noted in the previous chapter, any increase in cropland beyond the amount used in 1975 and 1976 likely would require conversion to crops of land now in other uses. That land generally is believed to be less productive and much of it more exposed to erosion than present cropland. Consequently, if pesticide regulations push farmers toward greater adoption of land-using technologies, both the economic and environmental (erosion) costs of production would be likely to rise.

There may be important tradeoffs, therefore, between erosion control policies and pesticide control policies since both are likely to lead to higher economic costs and each may impose higher environmental costs in terms of the other.

Fertilizer Policy Issues

In our judgment, prospective levels of fertilizer use, even in the high demand situation, will not pose major issues of environmental policy unless subsequent research demonstrates that nitrogen fertilizer does in fact do significant damage to the ozone shield. We assume in making this statement that effective policies to control erosion will be developed.

If the threat to the ozone shield is real, then use of nitrogen fertilizers could raise major policy issues. Until there are significant advances in the technology of biological nitrogen fixation, both in legumes and in grains--and they are not likely in the next ten to fifteen years--increasing world food production in accordance with demand will require substantial increases in consumption of nitrogen fertilizer. Restricting its use to prevent damage to the ozone shield at best would mean increasing malnutrition in poor countries,

and at worst could mean significantly more deaths by starvation. The tradeoffs in such circumstances would be stark and grim.

The choices will be even less promising if Aldrich is right in arguing that the nitrogen effect on stratospheric ozone is attributable to all sources of fixed nitrogen, not just chemical fertilizers.[66] In this case finding substitutes for these fertilizers, such as improved biological nitrogen fixation in legumes, will not necessarily reduce the threat to the ozone shield. As Aldrich points out, the only effective policies in this event would be reducing the rate of increase in demand for food by bringing population growth in the developing countries under control, and by improving the efficiency of crop uptake of available nitrogen, whether in the form of chemical fertilizer or through biological fixation. Improving efficiency may be a feasible policy, particularly if nitrogen fertilizer prices rise, but policies to control population growth at best take effect only over long periods of time.

The policy issues in attempting to deal with this problem would be especially complex because the threat, if there is one, is posed by world-wide use of nitrogen fertilizer. Consequently, restricting the use of these fertilizers in the United States alone would do little to solve the problem. International cooperation would be required. Unless the scientific evidence that there is a threat were overwhelming, achieving the necessary cooperation likely would be very difficult. Even if the evidence were clear there might be no agreement on how to weigh prospective deaths from skin cancer relative to illnesses and deaths from malnutrition and starvation. Since it is the white-skinned (wealthy) populations of the world who would suffer most of

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[66] Aldrich, "Perspectives on Nitrogen." Since this was written a report by the Council on Agricultural Science and Technology (Effect of Increased Nitrogen Fixation) has taken the same position as Aldrich on this issue.

the increased cancer and the dark-skinned (poor) populations who would go hungry, the likelihood of differing valuations of the tradeoffs would be high.

Clearly, more research is needed on the threat of nitrogen fertilizers to the ozone shield. Until more knowledge of the threat is in hand, discussions of policies for dealing with it are fruitless.

Salinity Policy Issues

Policy responses to the worsening salinity problems should be sought simultaneously on two levels--the overall management of a region's land and water supplies and the farmers' water management practices. The link between effective salinity control and total land and water management is evident in the Colorado River Basin. As was noted above, management of the Colorado River is confronted with two basic and interrelated problems--satisfying an increasing demand for water within the region and improving the quality of water, especially in the lower basin. The laws and agencies currently governing the distribution and use of water are unable to resolve these problems in a manner consistent with the long-term interests of the region as a whole. In fact, the law aggravates the situation by (1) encouraging states in the upper basin with water rights in excess of current use to increase use to protect their claims, and (2) failing to make upstream states and individuals responsible for the effects of their actions on the quality of the water downstream. Even though the basin includes parts of seven states as well as a section of northwest Mexico, no federal agency has the authority or technical capacity to identify and implement the measures required to deal with the worsening water quality and supply problems. A number of *ad hoc* projects such as the proposed desalinization

plant for upgrading the water delivered to Mexico are emerging to fill the void. However, this approach is bound to be much more costly than a solution based on an overall analysis of the needs, resources, and problems of the entire basin.

The 1972 Amendments to the Federal Water Pollution Control Act take a first step towards control of agricultural water pollution. Section 104 calls for cooperation among federal agencies to "carry out a comprehensive study and research program to determine new and improved methods and the better application of existing methods of preventing, reducing, and eliminating pollution from agriculture, including the legal, economic, and other implications of the use of such methods." Section 208 requires state plans which include "a process to (i) identify, if appropriate, agriculturally and silviculturally related nonpoint sources of pollution, including runoff from manure disposal areas, and from land used for livestock and crop production, and (ii) set forth procedures and methods (including land use requirements) to control to the extent feasible such sources."[67] Millions of dollars of federal funds have been spent to help states identify their nonpoint sources of pollution and develop control plans.

Effective control of pollution from salinity eventually must deal with on-farm land use and water management practices. However, efforts to impose direct controls on irrigation return flows are apt to be difficult to implement and generally ineffective. Farmers adopt practices that are perceived to be in their own interest. Thus, rising water costs which encourage adoption of water conservation practices may be the most effective means of reducing these return flows. Water-conserving techniques will be more readily adopted if farmers are able to reduce the costs and other problems

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[67] U.S. Congress, "Federal Water Pollution Control Act Amendments."

commonly associated with use of these practices. Consequently, research designed to minimize the soil salinity resulting from a given water-conserving irrigation practice and to increase the returns from soils of a given salinity level are important elements of an overall program to handle the salinity problem.

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